1) Dynamic Protocol Stacks for Linux
2) Network Debugging Toolkit Netsniff-NG

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EPiCS Project (http://www.epics-project.eu/)

GTALUG, October 9, 2012

Zurich, Switzerland

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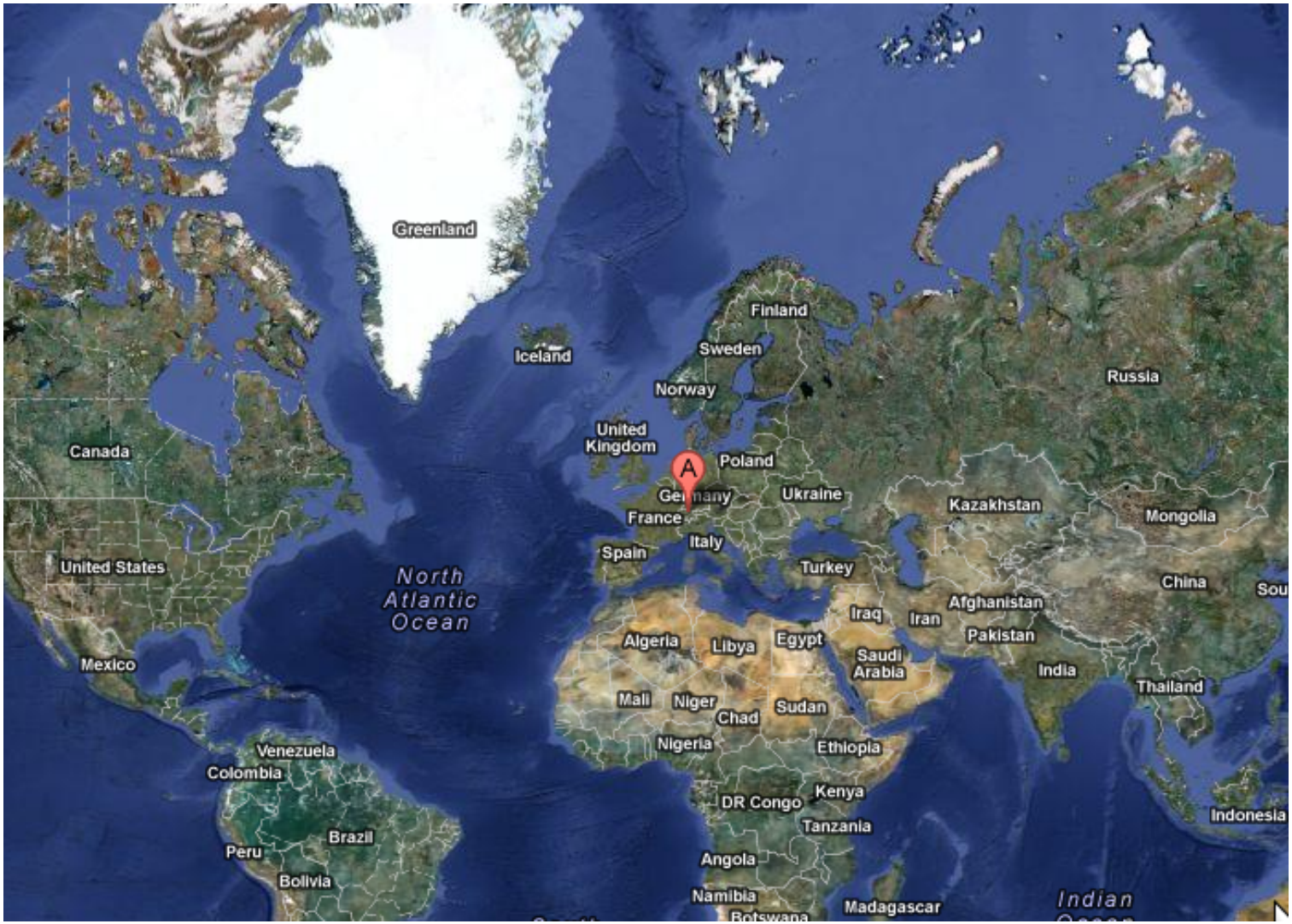

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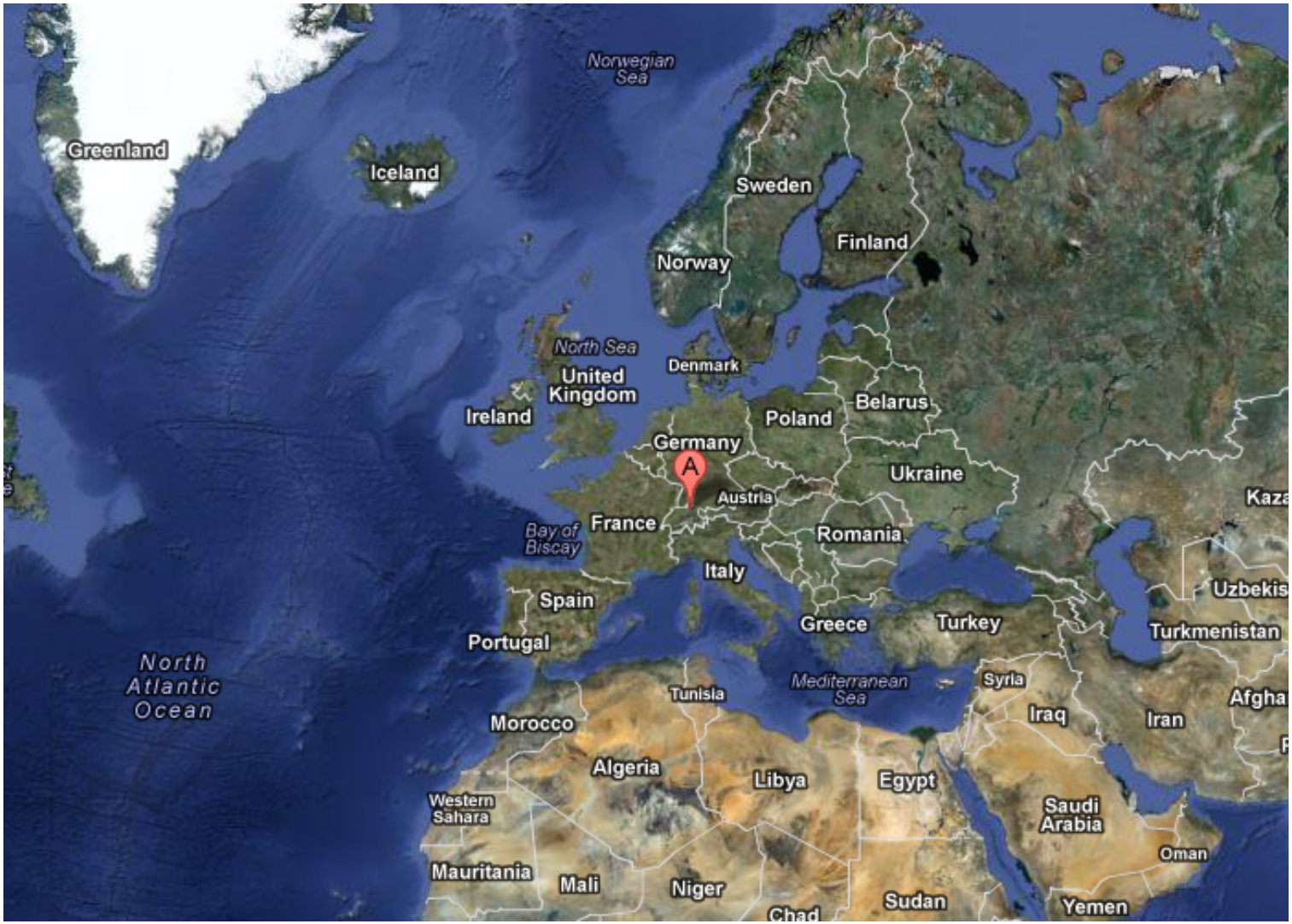

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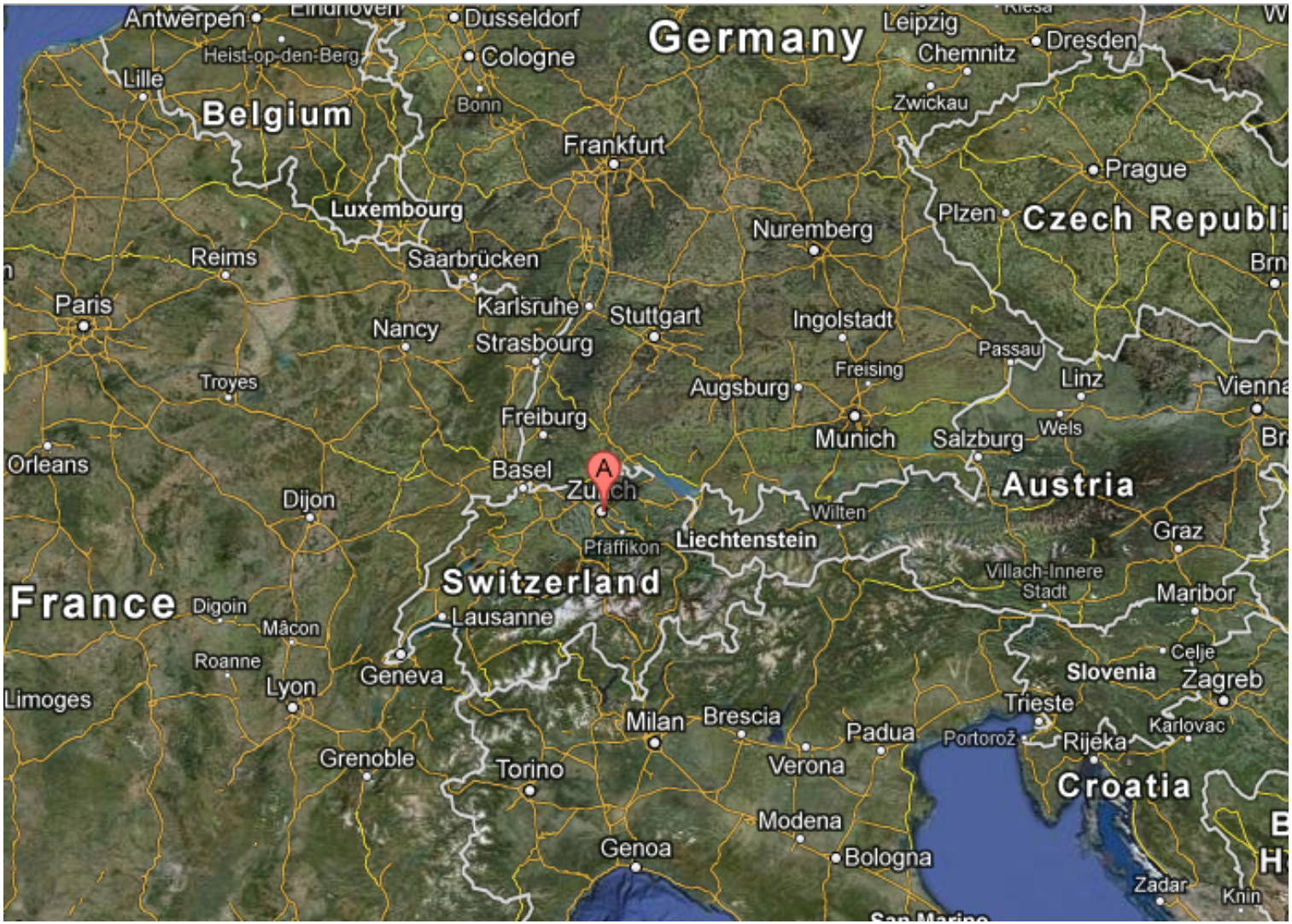

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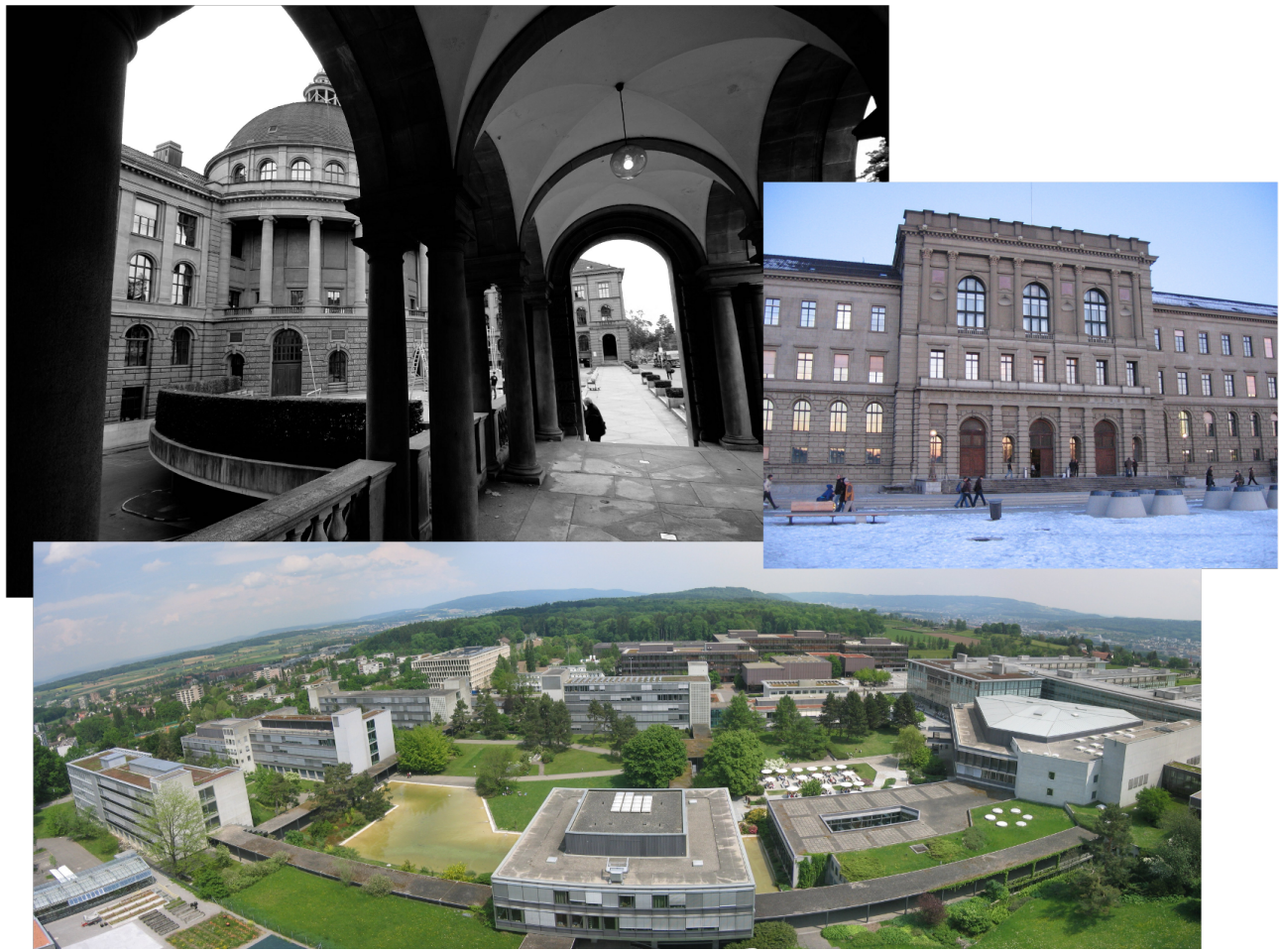

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Communication Systems Group

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- Performs research in ...
  - Wireless mobile networks and social networks
  - Network measurement and security
  - Future Internet architectures

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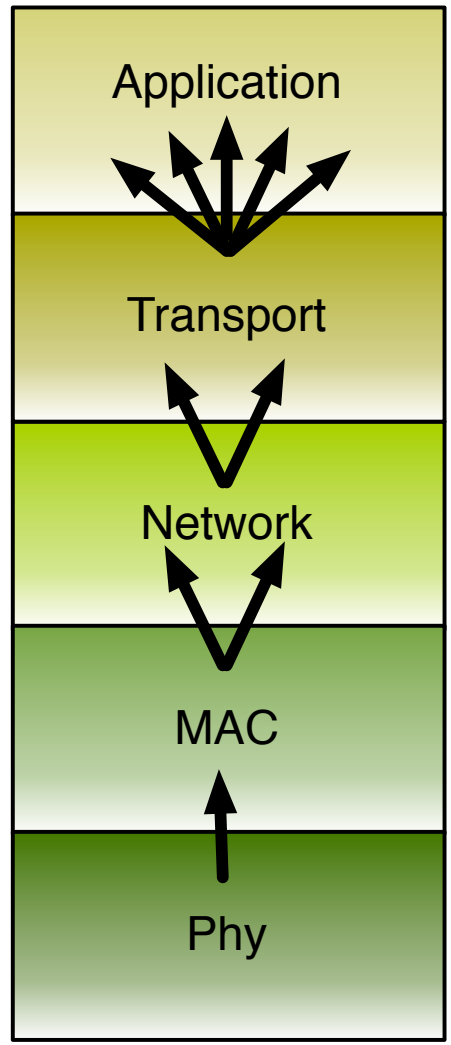
The Internet Architecture ...

- Static, layered model
- IP used as "glue" between application and physical layer



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... and its Limitations!

- Originally designed for a fixed infrastructure
- No provisions for resource limitations
- Difficult to integrate/deploy completely new network functionality
  - E.g. first IPv6 RFC from 1995
- Impossible to bypass unnecessary layers

$\rightarrow$ Leads to dedicated network architectures for e.g. sensor networks

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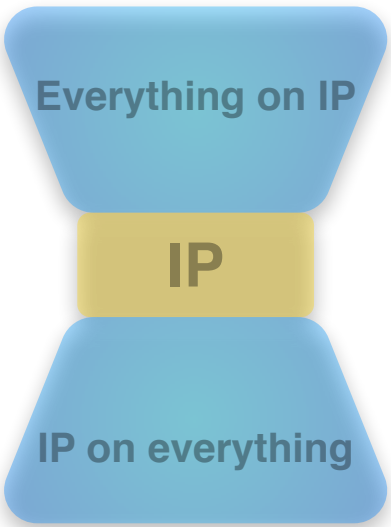
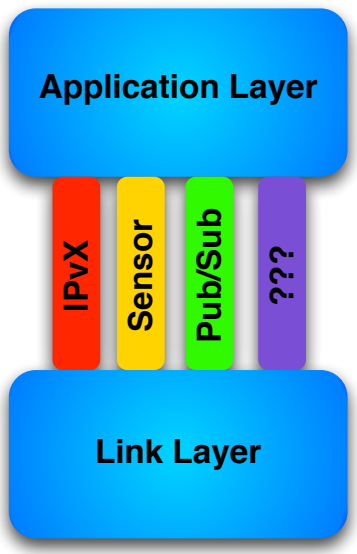
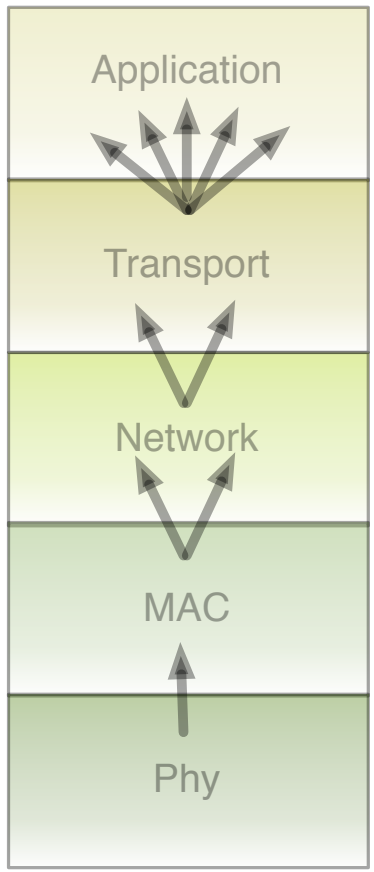
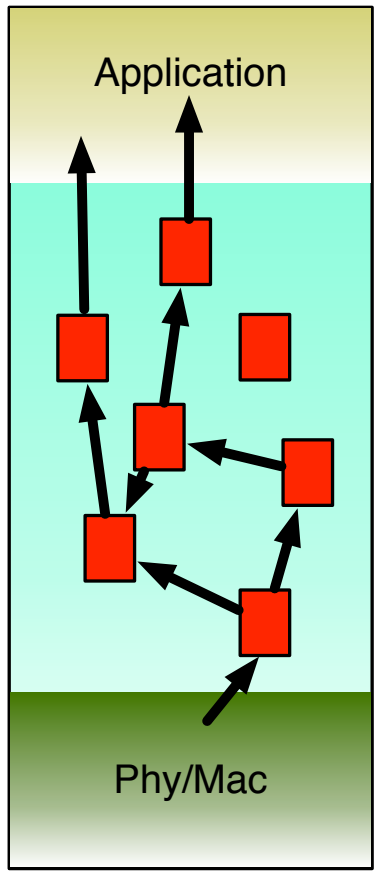
How would an Alternative look like?

- Here: clean slate architecture
- Meta-architecture does not enforce the protocols to be used
- Protocol functionality divided into "functional blocks" (FBs)









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What are the Benefits?

- One unified framework, where in each situation the optimal protocol stack can be built
  - Sensor networks vs. supercomputer interconnect
  - Servers, desktop nodes, embedded systems, ...
  - Pervasive computing: mobile phones, clothes, fridges, ...
- The protocol stack can be changed on the fly
  - Insert encryption, compression, reliability, ... on demand
  - Reboot-less updating of functionality, bugfixing
- New protocols can be added/deployed to the stack easily
- Probably, we can also put intelligence into the stack

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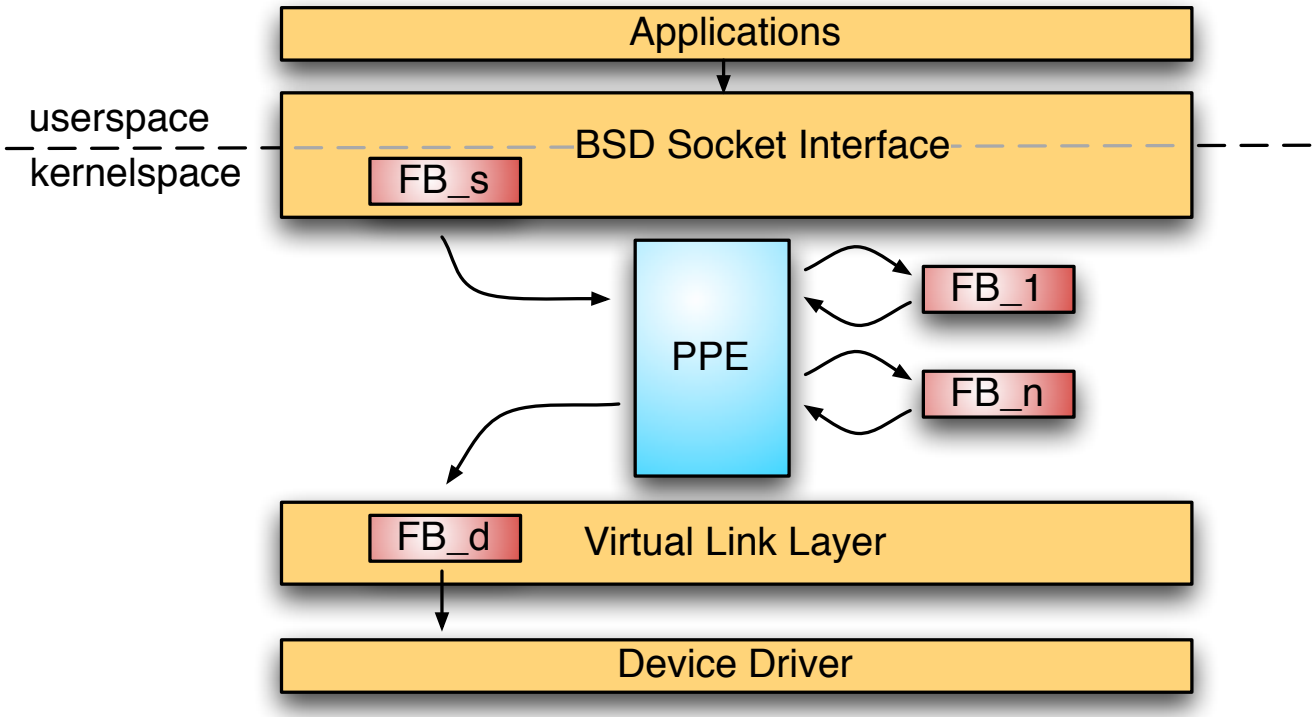
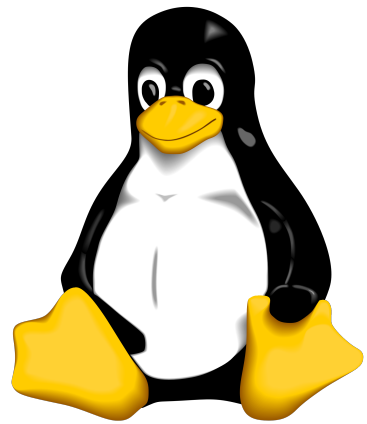
Architecture Design, Big Picture





- Implemented in the Linux kernel space
- Stack configuration from user space
- Question: when/how is our code invoked?

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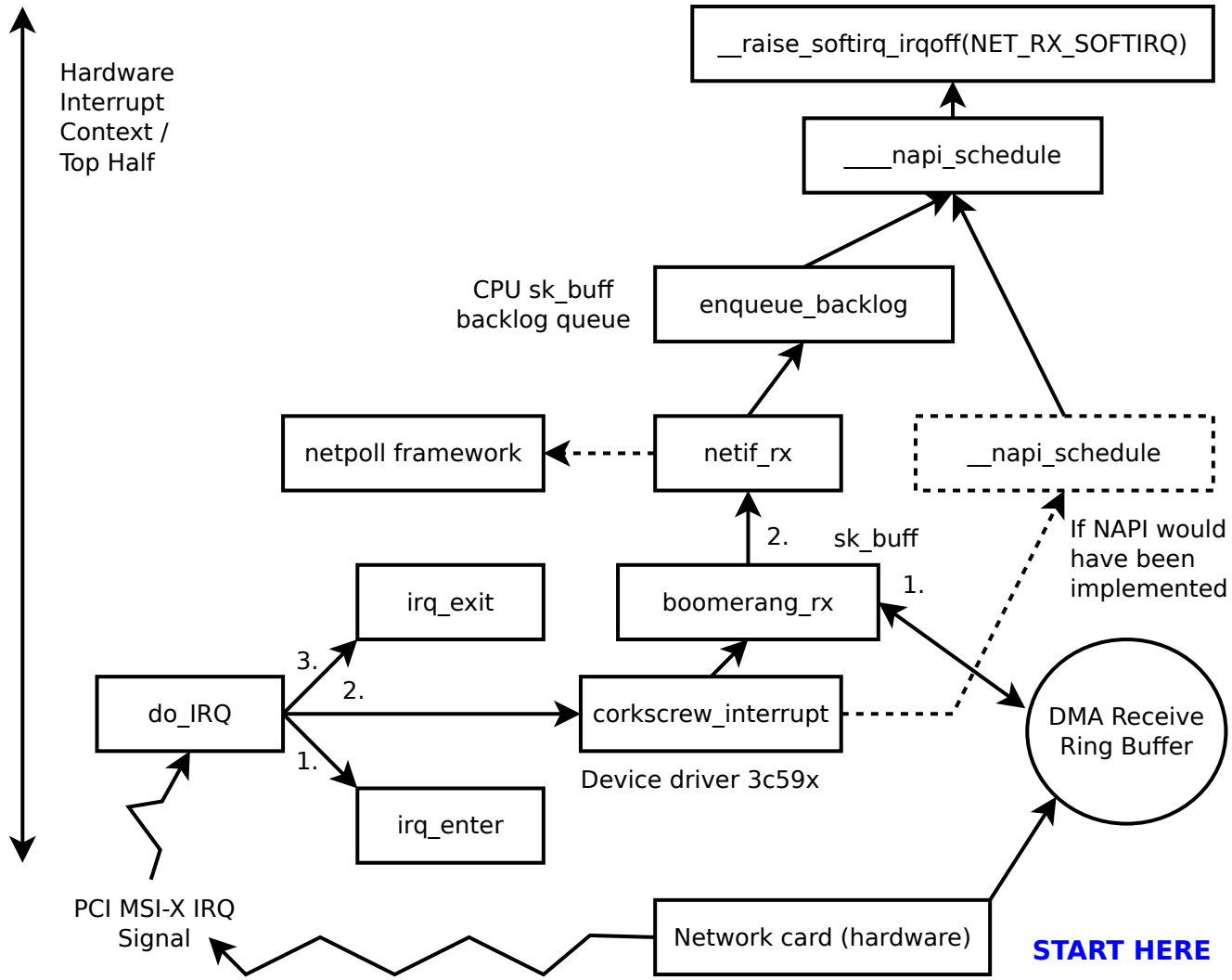
Linux Packet Processing Path, Ingress



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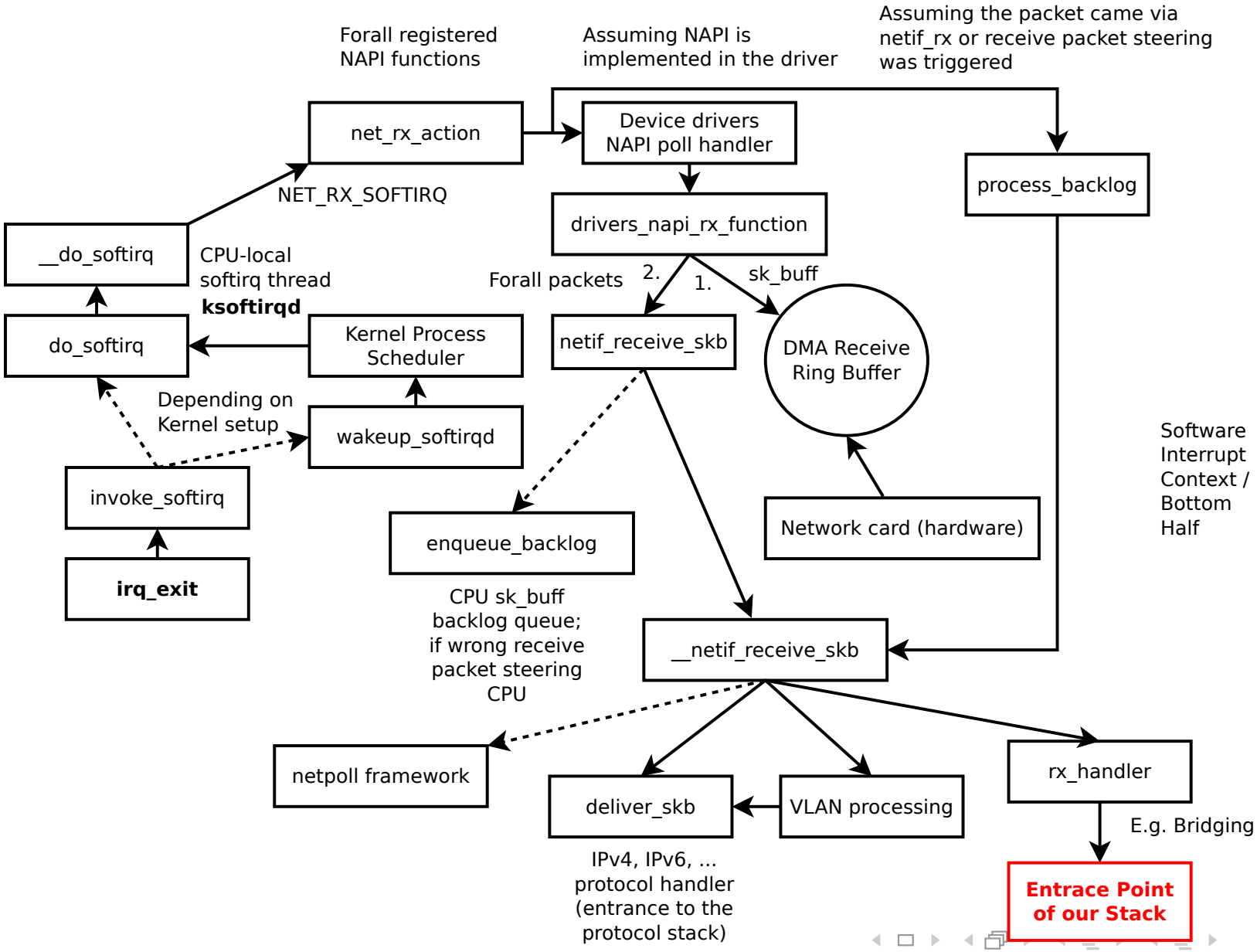
Linux Packet Processing Path, Ingress



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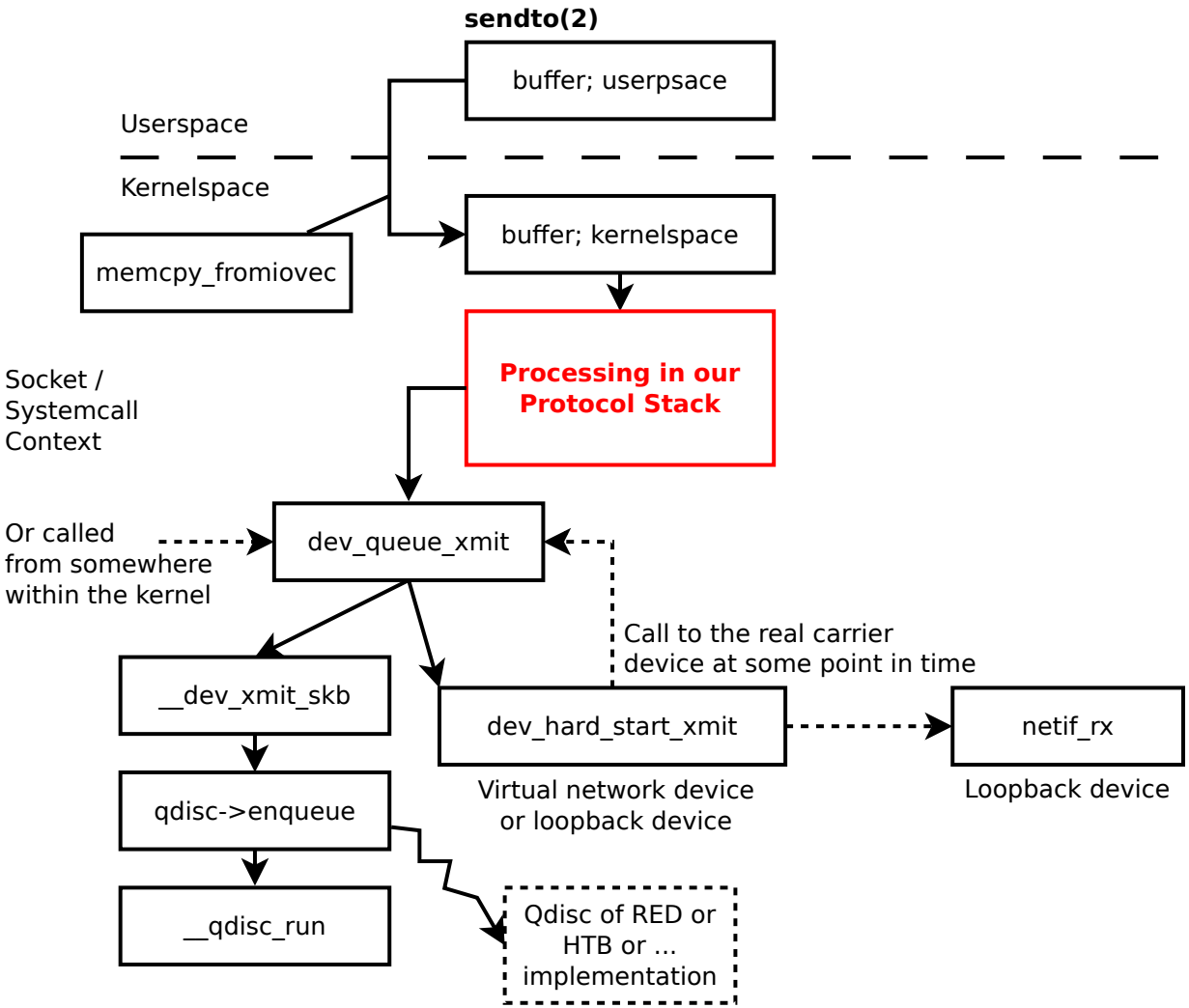
Packet Processing Path, Egress



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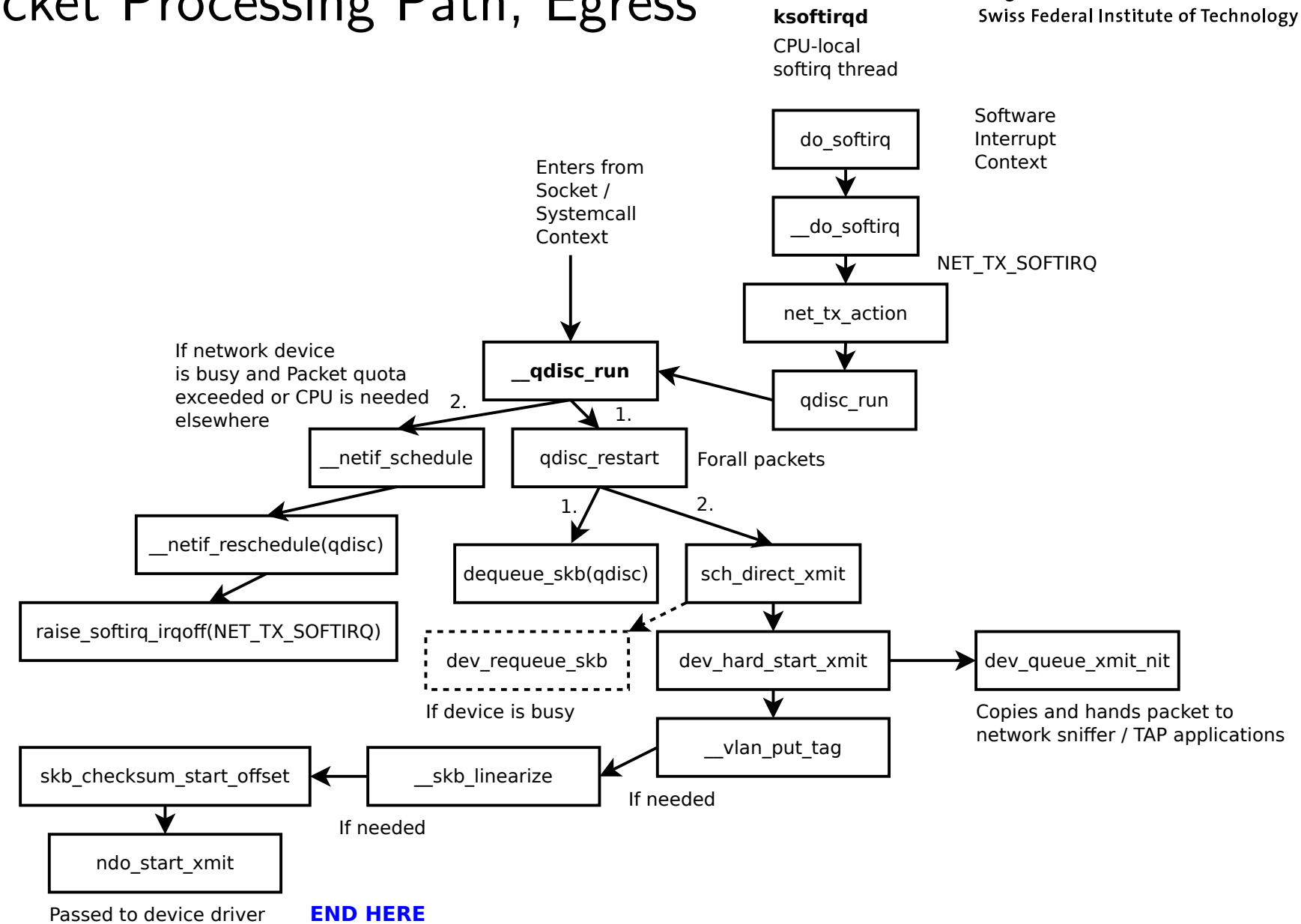
Packet Processing Path, Egress



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Implementation, General

- Concepts: modularity, layers of indirection
  - Functional blocks (fb)
  - Access to fbs via mapping (idp $\rightarrow$ pointer)
- PPE invoked from two different execution contexts
  - Per-CPU `ksoftirqd` (ingress)
  - CPU local socket system call (egress)
- Lightweight locking mechanisms and memory access all over the place
  - RCU locks
  - Sequential locks
  - Per-CPU “backlog” queues in PPE

Implementation, Functional Blocks

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- Current repository: `fb_eth`, `fb_irr`, `fb_bpf`, `fb_counter`, `fb_dummy`, `fb_otp`, `fb_tee`, `fb_pflana`
- (Manual) configuration example:
  - `fbctl add fb0 ch.ethz.csg.irr`
  - `fbctl add fb1 ch.ethz.csg.bpf`
  - `fbctl bind fb1 fb0`
  - `fbctl unbind fb1 fb0`
  - `fbctl rm fb1`

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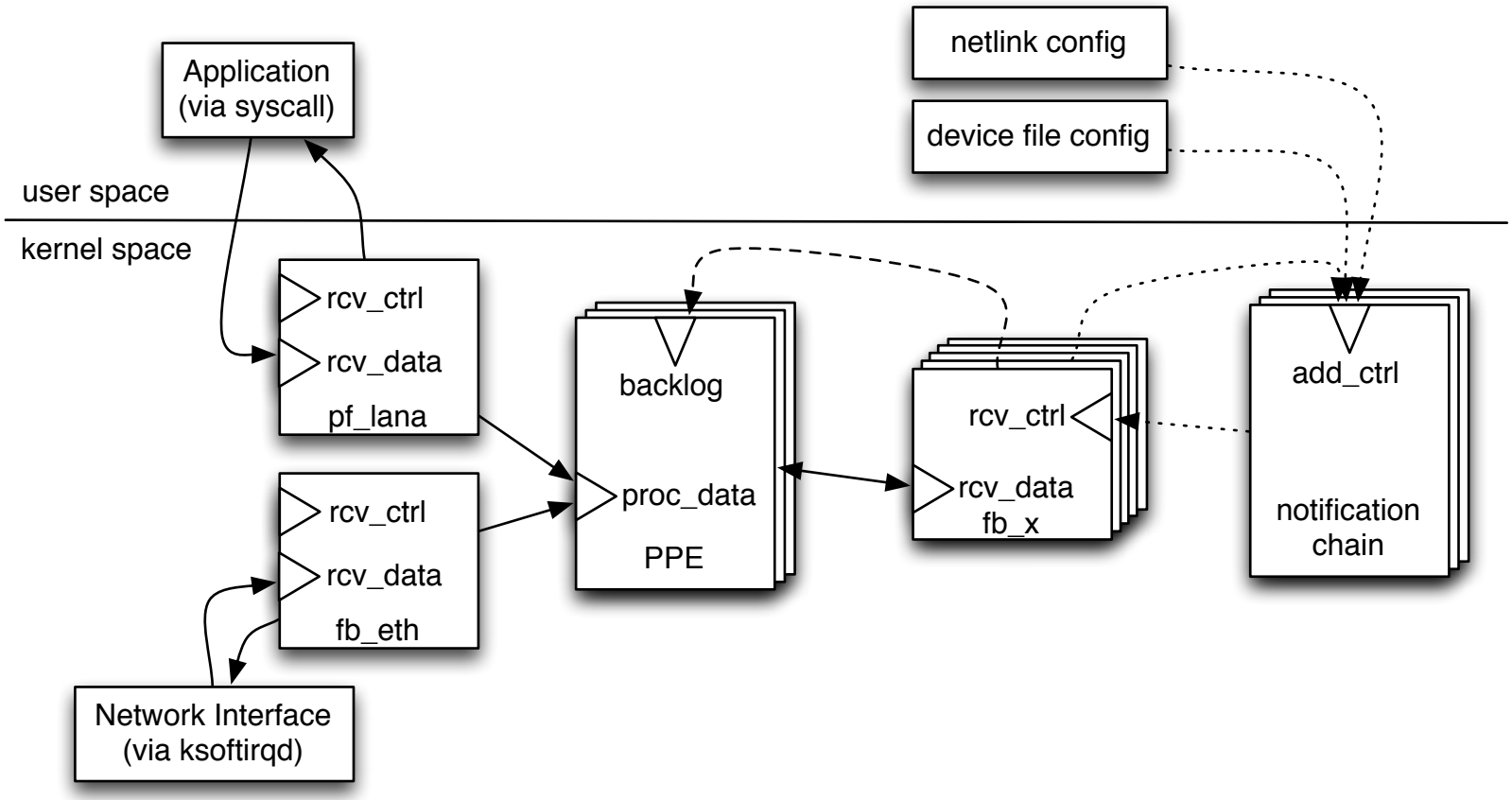
Implementation, Summary



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Implementation, Packet Handler Example

```
static int fb_dummy_netrx(const struct fblock * const fb,
             struct sk_buff * const skb, enum path_type * const dir)
{
    int drop = 0;
    unsigned int seq;
    struct fb_dummy_priv *fb_priv = rcu_dereference_raw(fb->private_data);

    do {
        seq = read_seqbegin(&fb_priv->lock);
        write_next_idp_to_skb(skb, fb->idp, fb_priv->port[*dir]);
        if (fb_priv->port[*dir] == IDP_UNKNOWN)
            drop = 1;
    } while (read_seqretry(&fb_priv->lock, seq));

    if (drop) {
        kfree_skb(skb);
        return PPE_DROPPED;
    }

    /* Do some protocol procesing ... */

    return PPE_SUCCESS;
}
```

```
struct fb_dummy_priv {
   idp_t port[2];
   seqlock_t lock;
}
```

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Implementation, Event Handler Example

```
static int fb_dummy_event(struct notifier_block *self,
                          unsigned long cmd, void *args)
{
    int ret = NOTIFY_OK;
    struct fblock *fb;
    struct fb_dummy_priv *fb_priv;

    rcu_read_lock();
    fb = rcu_dereference_raw(container_of(self, struct fblock_notifier, nb)->self);
    fb_priv = rcu_dereference_raw(fb->private_data);
    rcu_read_unlock();

    switch (cmd) {
    case FBLOCK_BIND_IDP:
        ...
        write_seqlock(&fb_priv->lock);
        fb_priv->port[msg->dir] = msg->idp;
        write_sequnlock(&fb_priv->lock);
        ...
        break;
     ...
    }
    return ret;
}
```

Evaluation, Stacks

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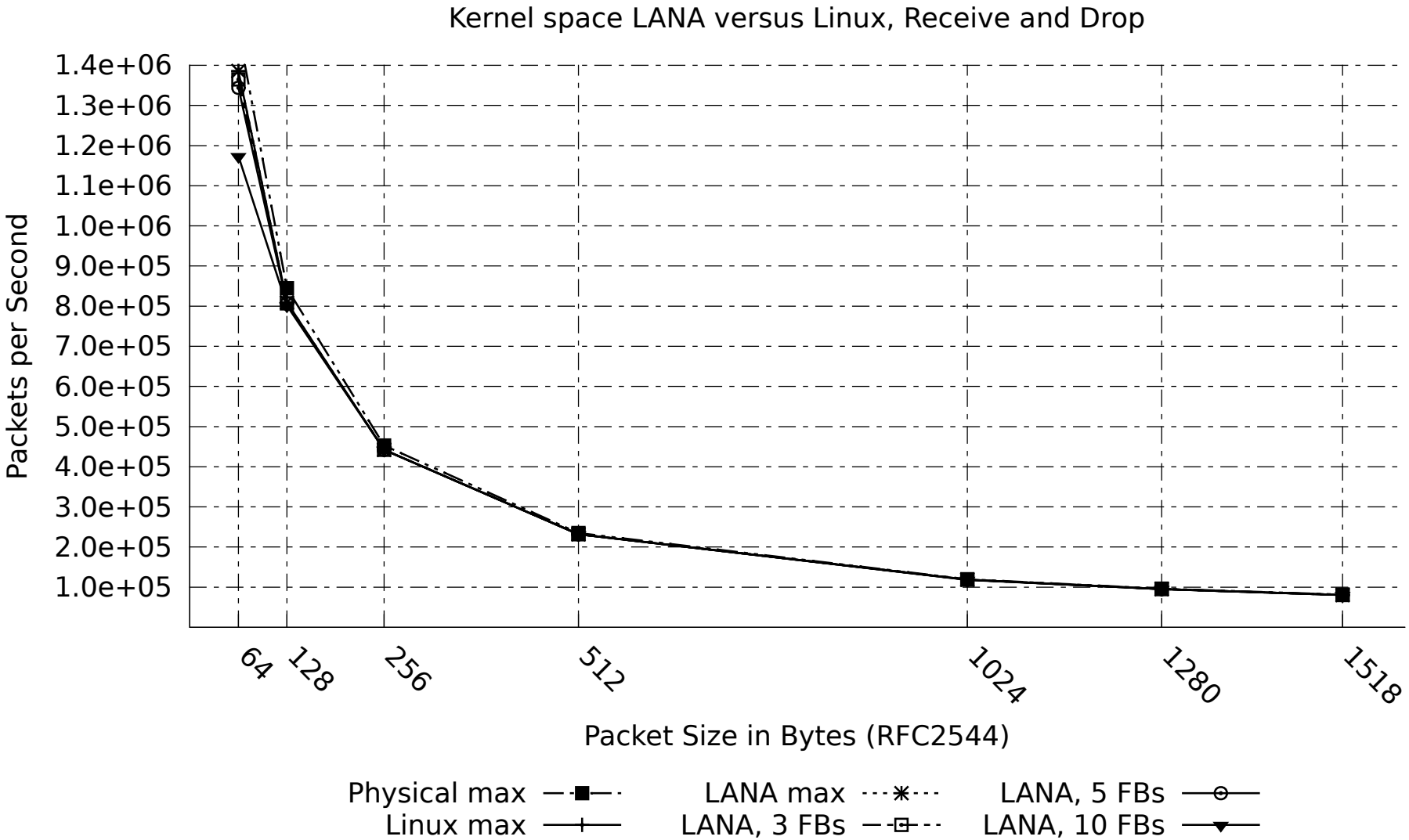

Evaluation, Sockets

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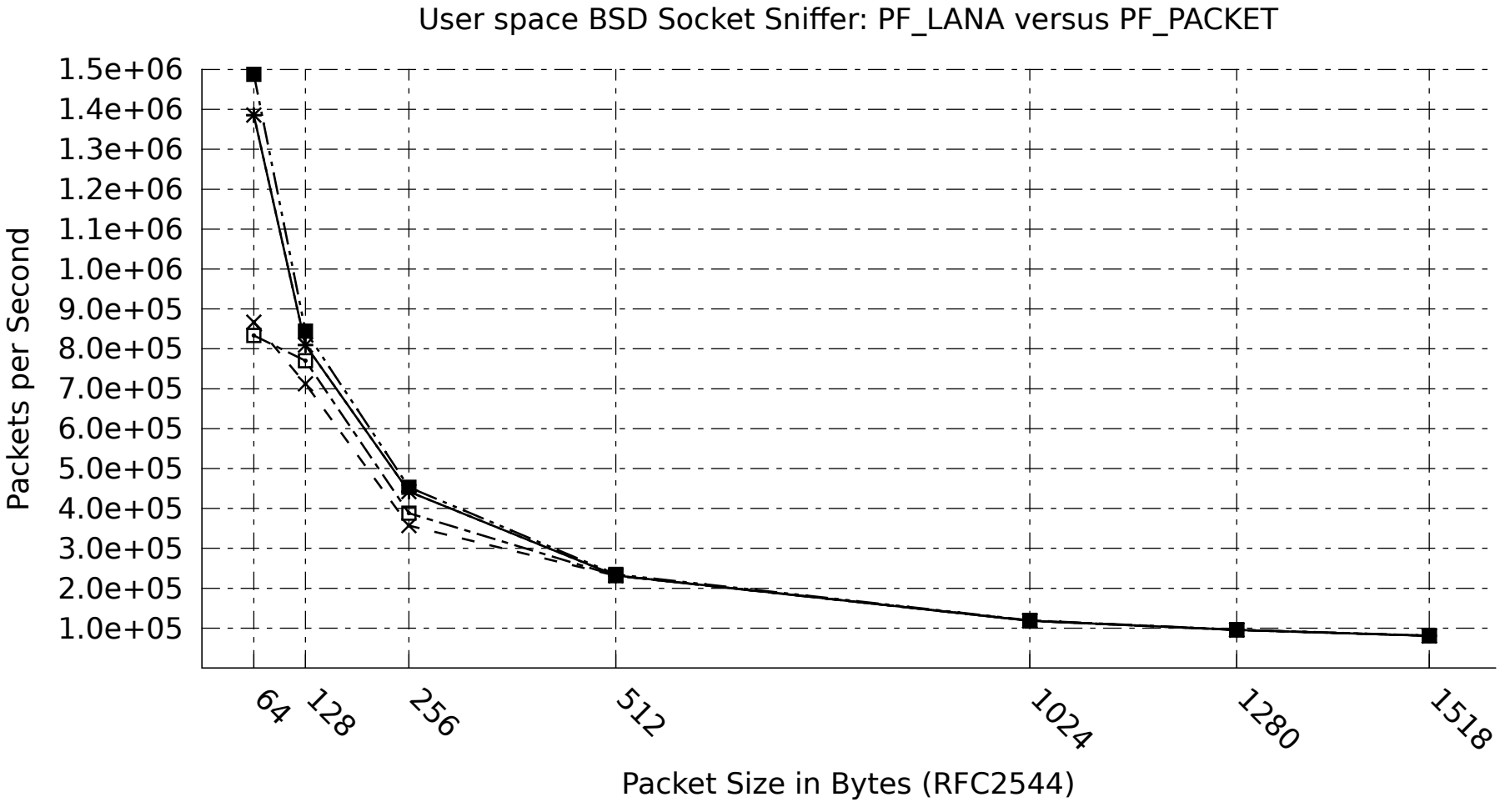

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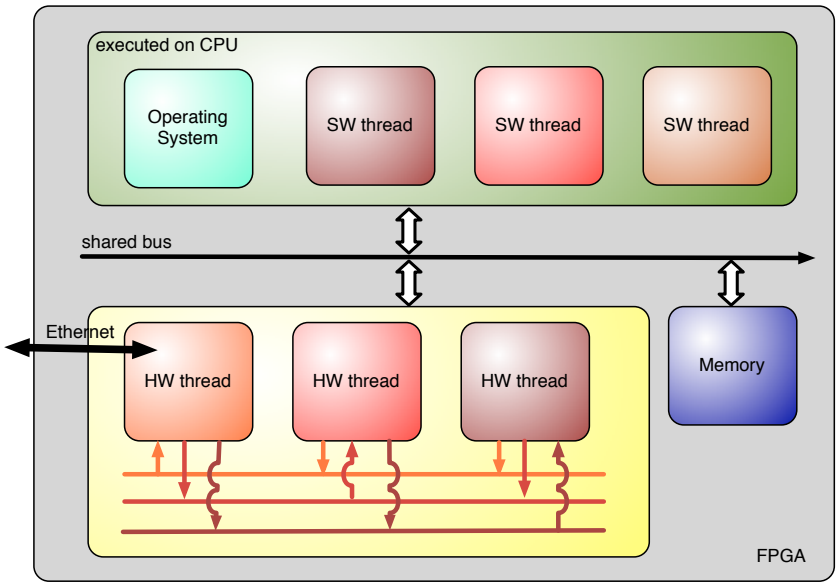
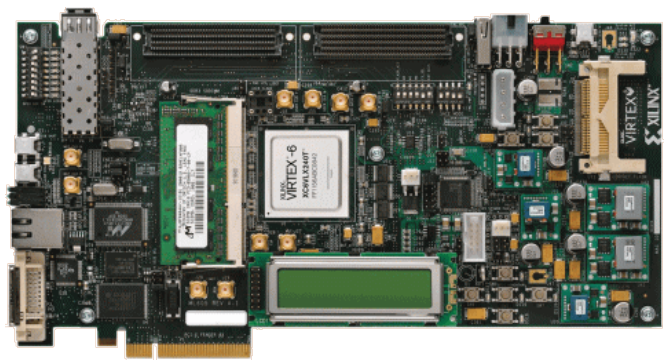
Taking this one Step further: Dynamic Hardware/Software Mapping of FBs

- During runtime, we want to dynamically map software FBs into hardware FBs and vice versa
- Reasons:
  - Better performance
  - Energy efficiency



- Hence, a node's stack can partly be in hardware, partly in software
- Xilinx ML605 (FPGA) Board, Xilinx partial reconfiguration (icap)



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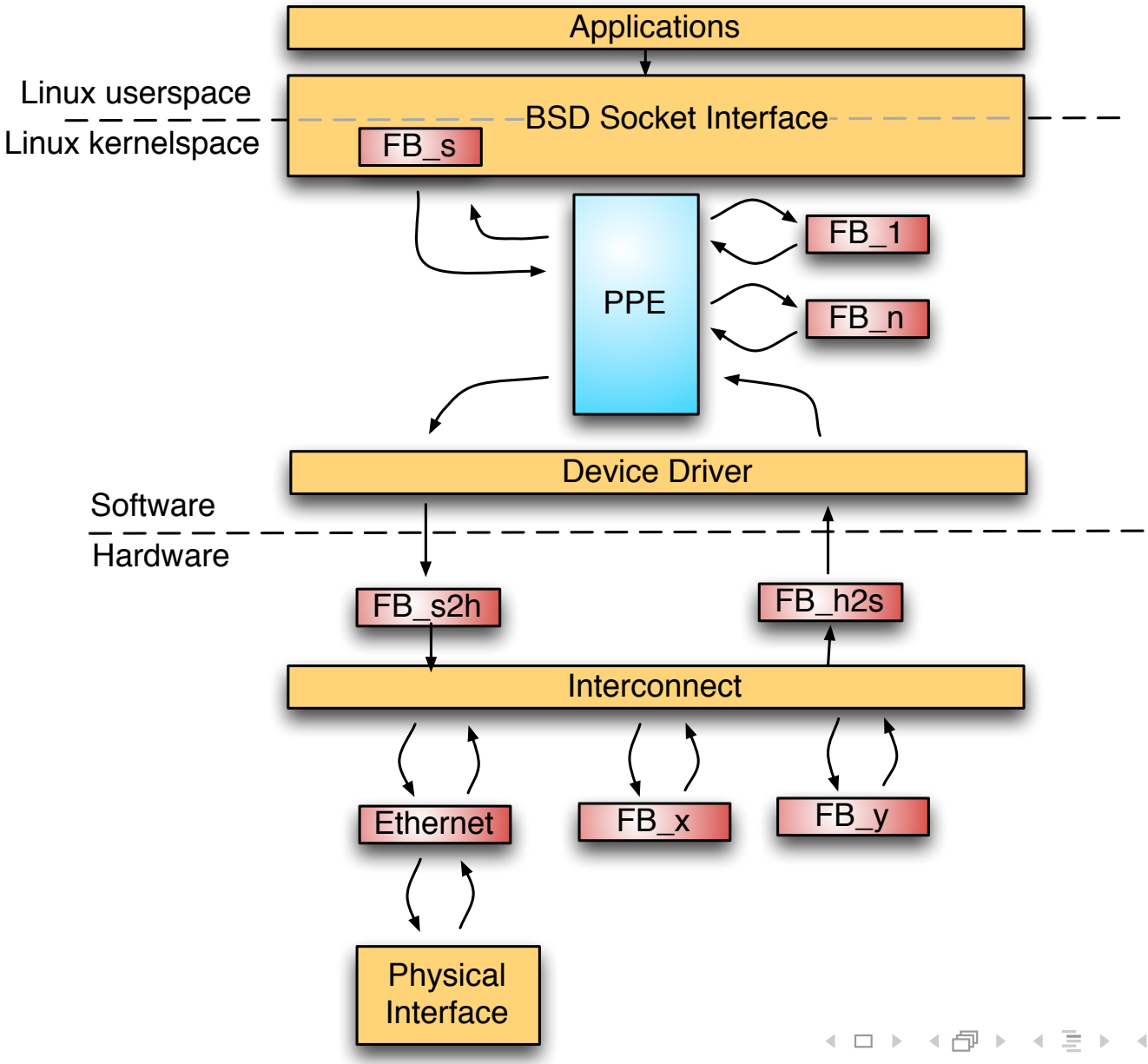
Architecture Design, Big Picture



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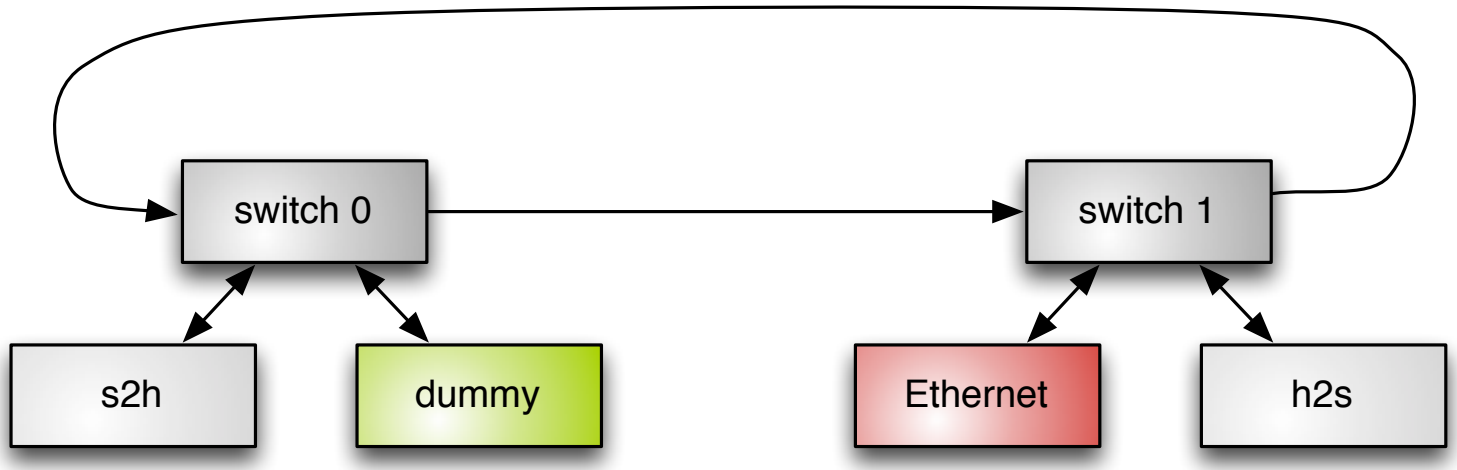
Implementation, General



- Line-rate Network on Chip (NoC) implementation in VHDL
- Possibility for runtime partial reconfiguration of FPGA
- Usage of ReconOS, reconfigurable OS based on Linux

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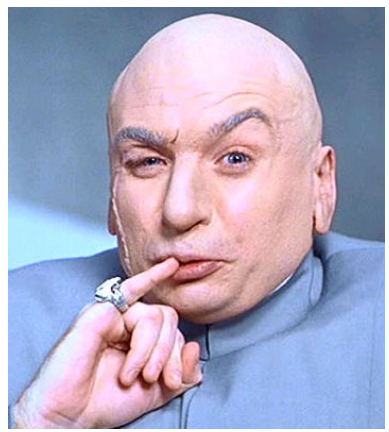
Lets go one layer up and have a look at the user space!

- Now that we have a nice reconfigurable backend, it's time to make it more intelligent!
- Especially for sensor nodes, we could adapt the stack dynamically to environmental changes ...
  - E.g. battery lifetime vs. performance
- 2 new tools: `sensord`, `configd`
  - `sensord`: collection and analysis of sensor data
  - `configd`: stack builder, (re)configuration engine



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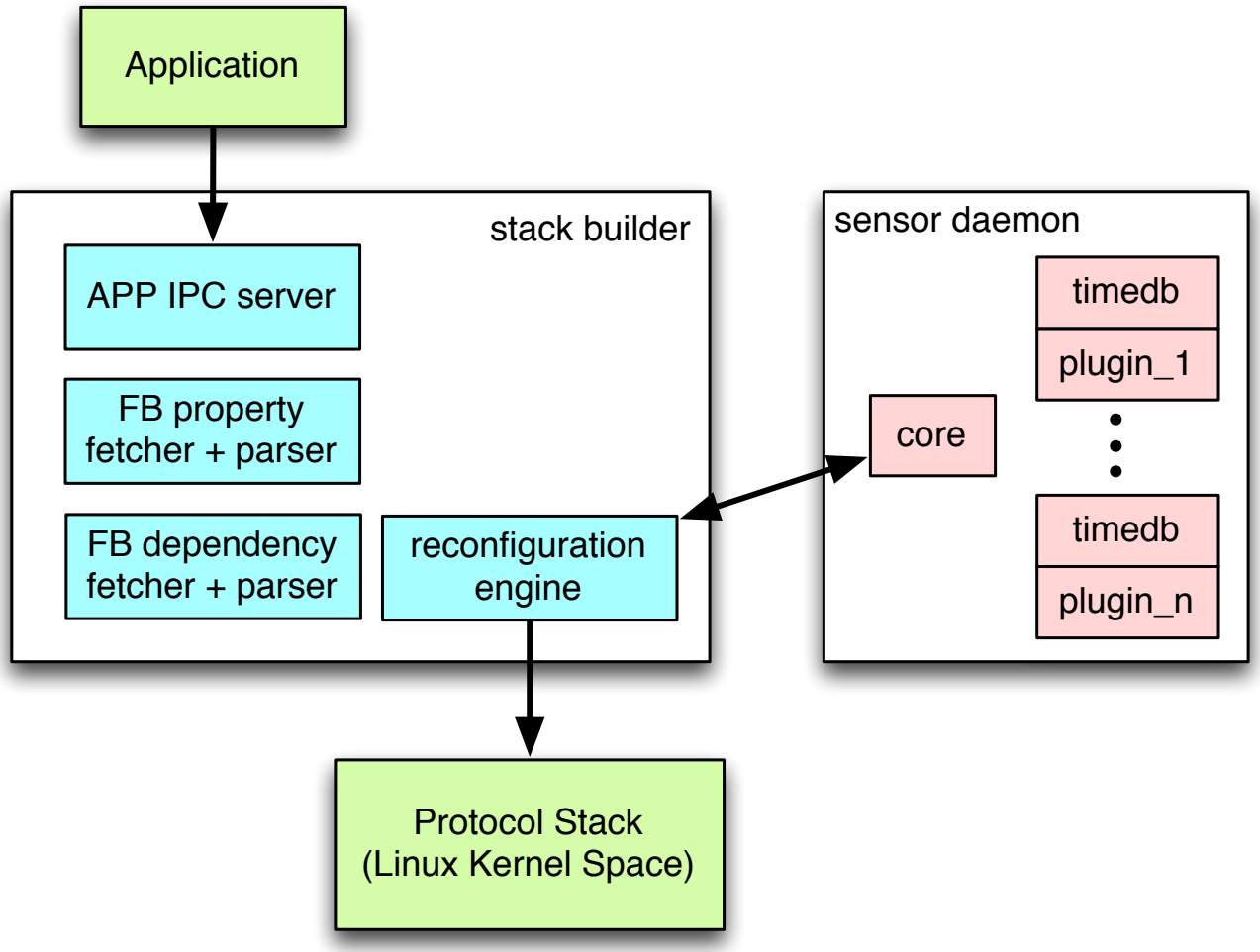
sensord and configd



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sensord Implementation

- Executable with collection of plugins as shared objects
- Plugins dynamically pluggable during runtime
- Scheduling via internal timer delta queue
- Collected data values stored in `timedb` round robin database (no, not RRDtools!)
- Clients can register for "threshold exceeded" notifications
  - Registration via Unix domain sockets
  - Notification alarm via SIGUSR1, SIGUSR2 (lower, upper thresholds)
  - Plugin and measurement value passing via shared memory

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sensord Plugin Example, 1

```
static void dummy_fetch(struct plugin_instance *self)
{
    int i;
    for (i = 0; i < self->cells_per_block; ++i) {
        self->cells[i] = ((double) rand() / (double) RAND_MAX);
    }
}

struct plugin_instance dummy_plugin = {
    .name            = "dummy-1",
    .basename        = "dummy",
    .fetch           = dummy_fetch,
    .schedule_int    = TIME_IN_SEC(1),
    .block_entries   = 1000000,
    .cells_per_block = 2,
};
```

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sensord Plugin Example, 2

```
static __init int dummy_init(void)
{
    struct plugin_instance *pi = &dummy_plugin;

    srand(time(NULL));
    pi->cells = xmalloc(pi->cells_per_block * sizeof(double));

    return register_plugin_instance(pi);
}

static __exit void dummy_exit(void)
{
    struct plugin_instance *pi = &dummy_plugin;
    free(pi->cells);
    unregister_plugin_instance(pi);
}

plugin_init(dummy_init);
plugin_exit(dummy_exit);

PLUGIN_AUTHOR("Daniel Borkmann <daniel.borkmann@tik.ee.ethz.ch>");
PLUGIN_DESC("A simple dummy sensord plugin");
```

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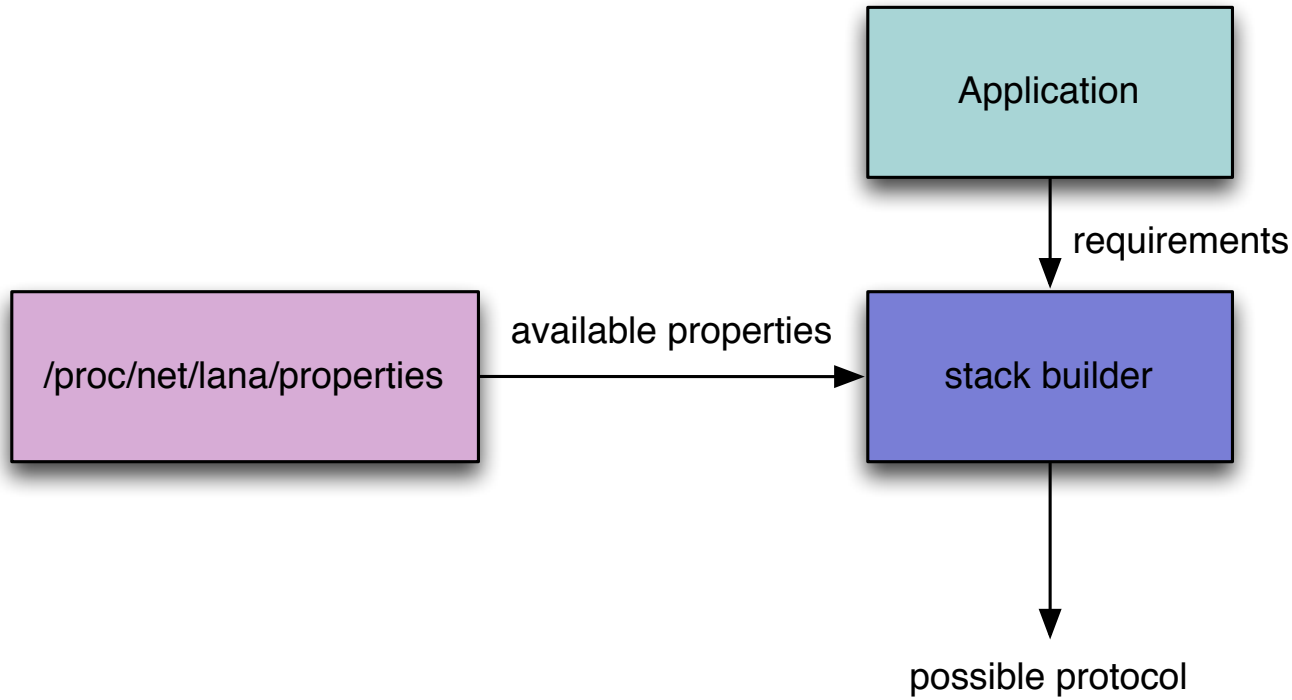
configd, Big Picture



- Applications register their PF_LANA sockets to configd
- `configd` registers itself to `sensord`, e.g. for wireless link quality notifications

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configd, Application Registration

```
int main(void)
{
    ...
    sock = socket(PF_LANA, SOCK_RAW, 0);
    if (sock < 0)
      panic("Cannot create socket!\n");
    ...
    memset(buff, 0, sizeof(buff));
    bmsg = (struct bind_msg *) buff;
    strlcpy(bmsg->app, "temp-sensor");
    bmsg->props[0] = RELIABILITY;
    bmsg->flags = TYPE_CLIENT;

    /* Query kernel space fblock name */
    ret = ioctl(sock, SIOFBNAM, bmsg->name);
    ...
    ret = bind_config(bmsg);
    ...
    ret = sendto(sock,data,len,0,NULL,0);
    ...
    close(sock);
    return 0;
}
```

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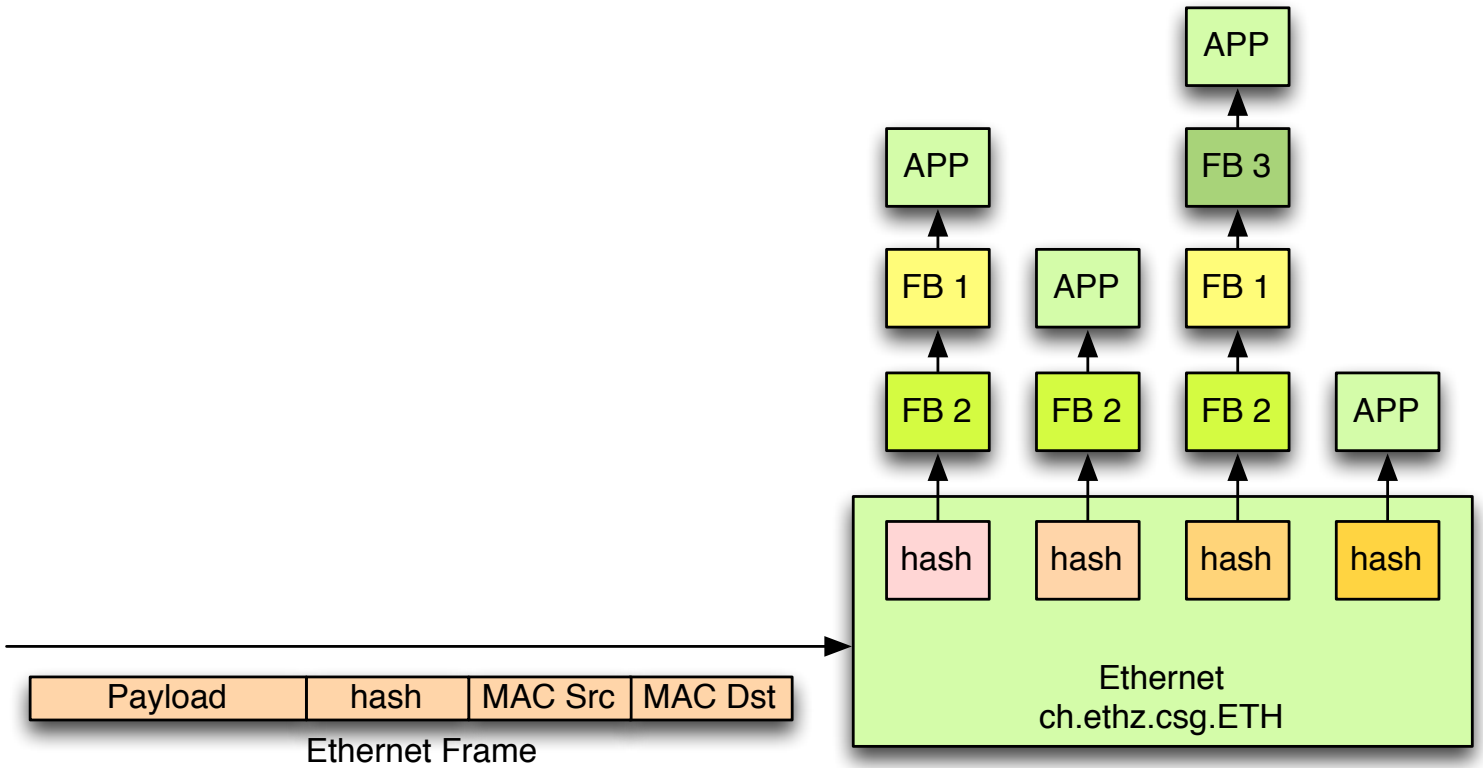
Internode Communication

- Now we have the backend, `sensord`, `configd`, but how do nodes talk with each other?



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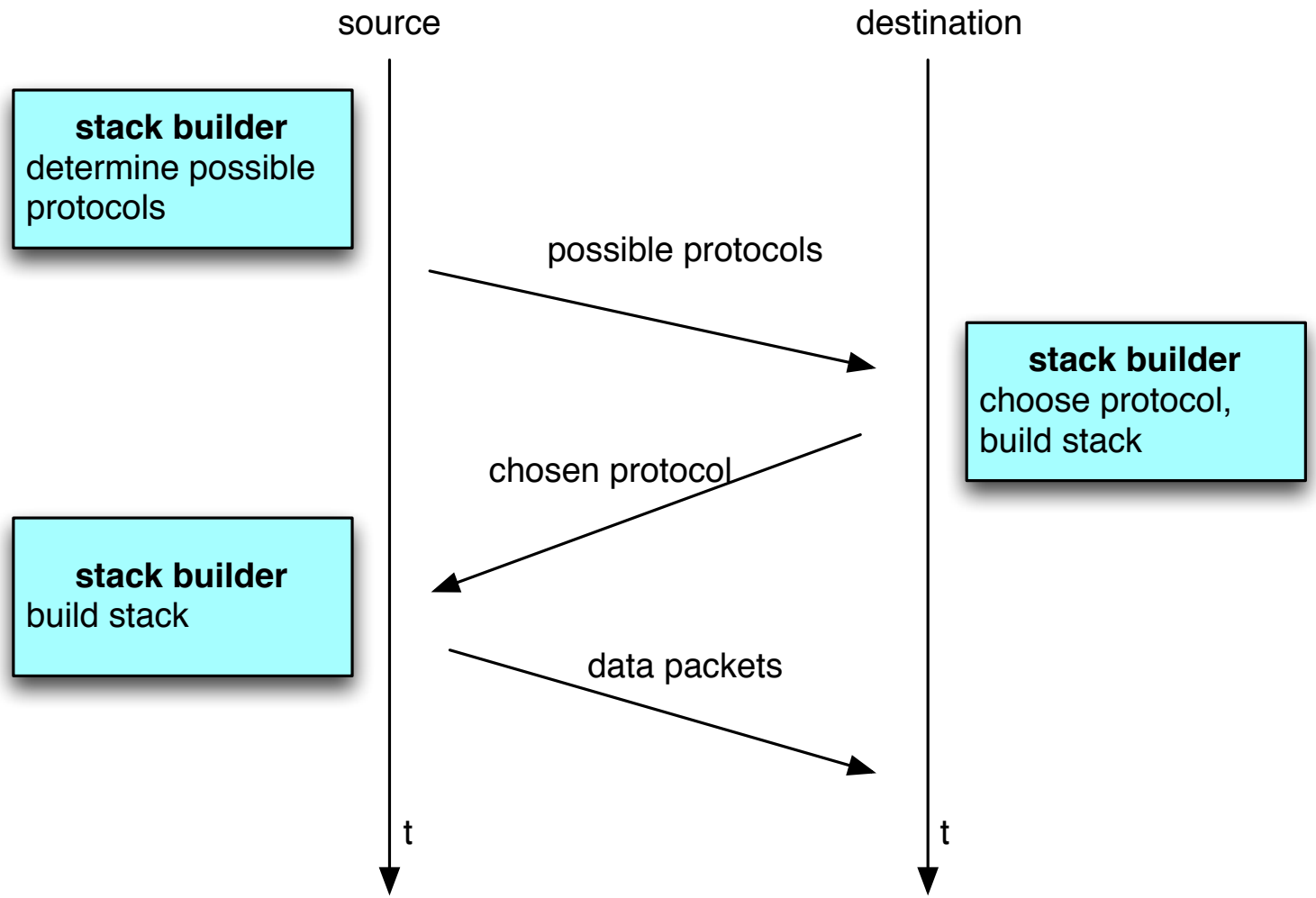
Internode Stack Reconfiguration, 1



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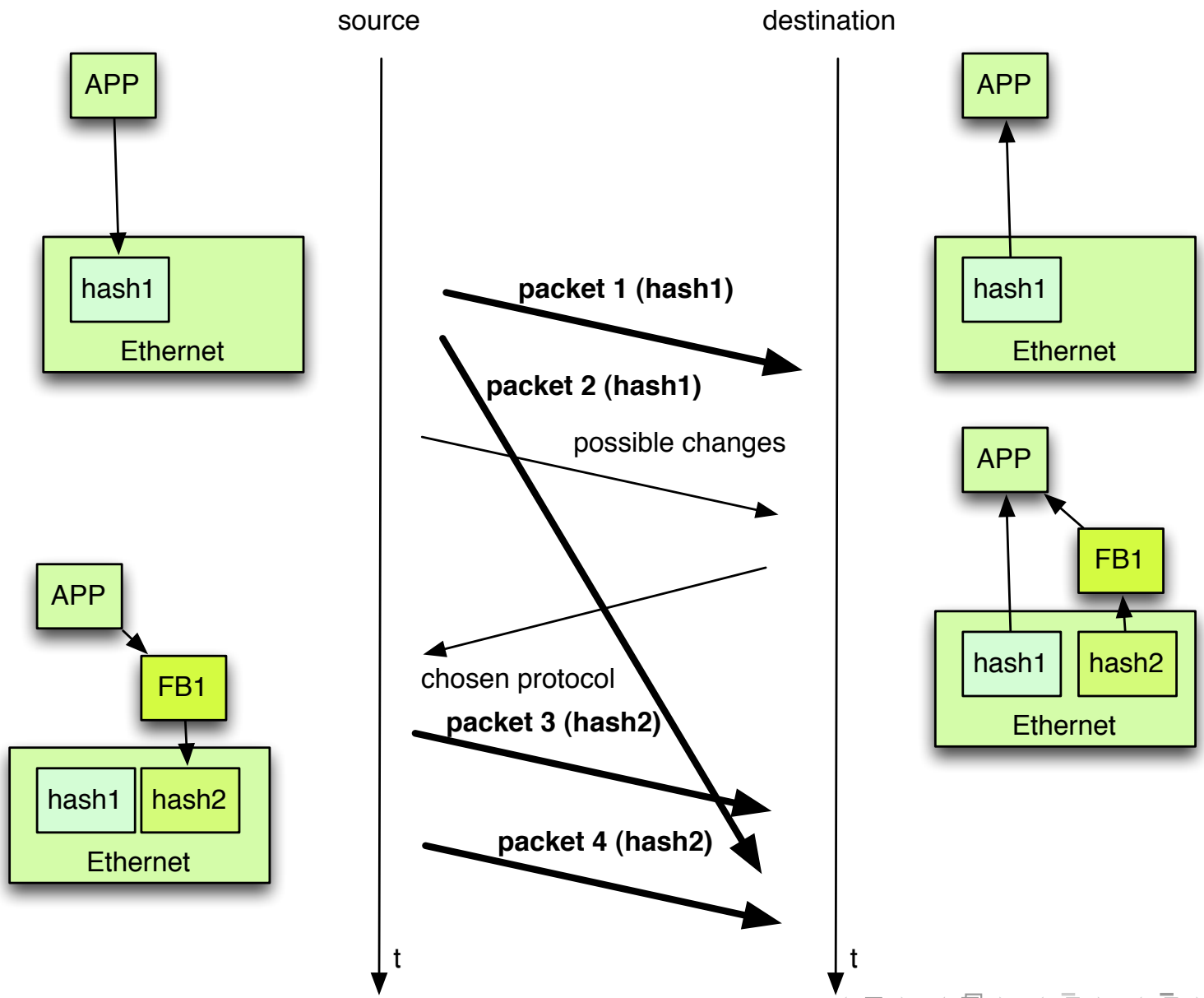
Internode Stack Reconfiguration, 2



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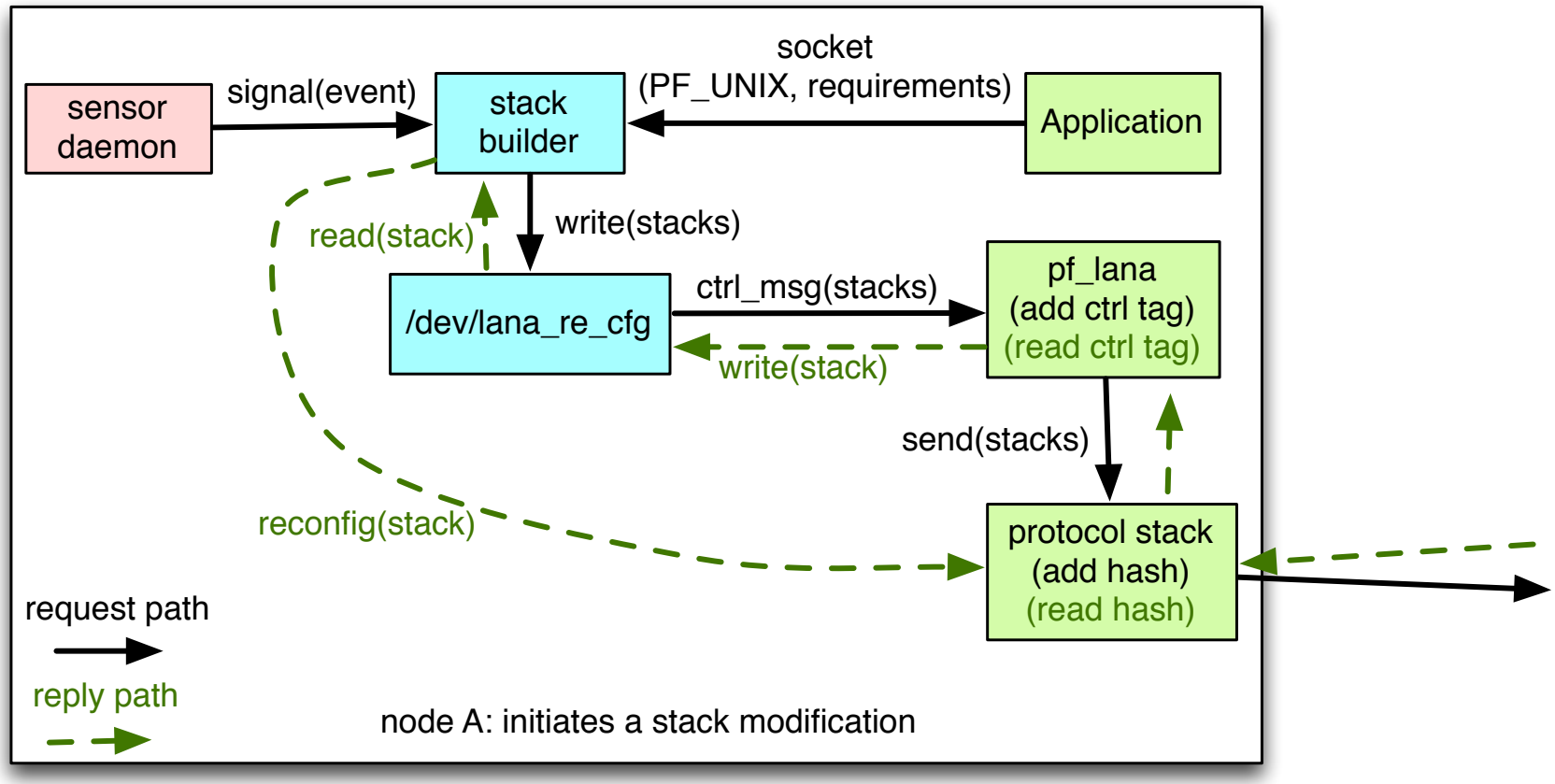
Internode Stack Reconfiguration, Impl.



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Example Scenario

- Two (or more) nodes, connected over wireless
- Periodically exchange (e.g.) temperature information
- Transmission has to be reliable
- Nodes run on battery, aim also to be energy-efficient
- Testlab experiment:
  - `sensord` with link-quality plugin, that notifies `configd`
  - Triggers `fb_irr` to be included when needed resp. excluded when not

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Source Code

- Prototype implementation released under GPLv2.0
- Directly included into ReconOS
- Github: `https://github.com/EPiCS/reconos`
- Research publications:
  - `http://www.epics-project.eu/`
  - `http://www.csg.ethz.ch/people/arkeller`
  - `http://borkmann.ch/`

High-Performance Network Debugging

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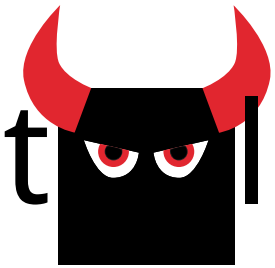
netsniff-ng t  lkit

- **netsniff-ng**, a high-performance zero-copy analyzer, pcap capturing and replaying tool
- **trafgen**, a high-performance zero-copy network traffic generator
- **mausezahn**, a packet generator and analyzer for HW/SW appliances with a Cisco-CLI
- **bpfc**, a Berkeley Packet Filter (BPF) compiler with Linux extensions
- **ifpps**, a top-like kernel networking and system statistics tool
- **flowtop**, a top-like netfilter connection tracking tool
- **curvetun**, a lightweight multiuser IP tunnel based on elliptic curve cryptography
- **astraceroute**, an autonomous system (AS) trace route utility

The Toolkit

- *Here:* focus on netsniff-ng, trafgen, mausezahn
- Used to debug and stress-test our dynamic protocol stack
- Rx/Tx zero-copy: no copies between kernel and user space
- Users reported higher capturing/transmission rates on 1-10 Gbps than commonly used tools (tcpdump/libpcap, Wireshark, ...)
- Part of all the big distributions, plus Backtrack, GRML, Xplico, NST, Alpine Linux, Scientific Linux/CERN

netsniff-ng

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- High-performance traffic analyzer, replayer
- PCAP files compatilbe with tcpdump, Wireshark, ...
- `netsniff-ng --in eth0 --out dump.pcap -s -b 0`
- `netsniff-ng --in wlan0 --rfraw --out dump.pcap -s -b 0`
- `netsniff-ng --in dump.pcap --mmap --out eth0 -s -b 0`
- `netsniff-ng --in eth1 --out /opt/probe/ -s -m -J --interval 30 -b 0`
- `netsniff-ng --in any --filter ip4tcp.bpf --ascii`

netsniff-ng, Filtering

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```
ldh [12]                          ; Load Ethernet type field
jeq #0x800, Cont, Drop            ; Check value against 0x800
Cont: ldb [23]                    ; Load IPv4 proto
jeq #0x6, Keep, Drop              ; Check against 0x6 (TCP)
Keep: ret #0xffffffff             ; Return packet
Drop: ret #0                      ; Discard packet
```

- `bpfc ip4tcp.bpfa > ip4tcp.bpf`, then pass it to `--filter`
- Or abuse tcpdump: `tcpdump -dd my-filter`
- Filtering done in the Linux kernel (BPF virtual machine)
- Newer kernels: BPF JIT for x86/x86_64, powerpc, sparc

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trafgen

- Low-level, high-performance traffic generator
- `trafgen --dev eth0 --conf packets.txf -b 0`
- `trafgen --dev wlan0 --rfraw --conf beacon.txf -b 0`
- `trafgen --dev eth0 --conf trafgen.txf -b 0 --num 10 --rand`
- Own configuration language:

```
{ 0x00, 0x01, 0x03, fill(0xff, 60), 0x04 }
{ 0x00, 0x01, 0x03, rnd(60), 0x04 }
{ drnd(64) }
{ 0x00, 0b00110011, 0b10101010, rnd(60), 0x04 }
```

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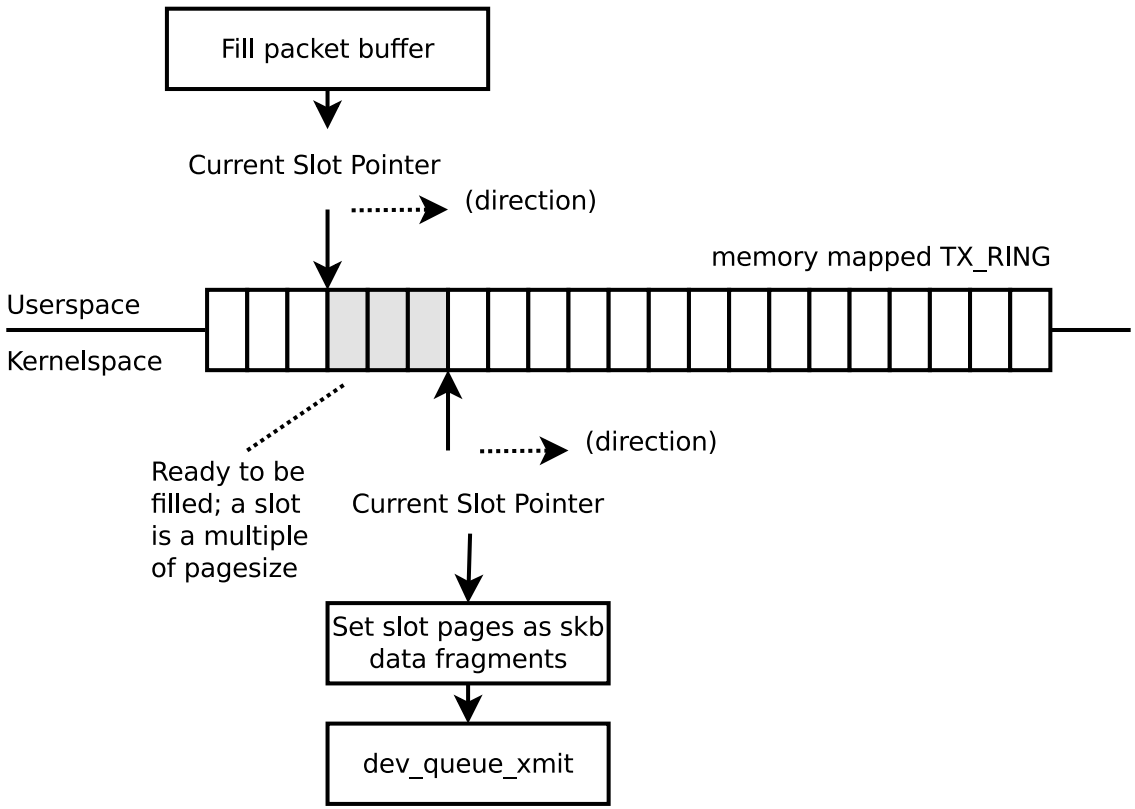
trafgen

- Uses PF_PACKET sockets with mmap(2)'ed TX_RING
- Users have reported wire-rate performance from user space
- Low-level packet configuration, more flexible than `pktgen`



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mausezahn

- High-level, (not so) high-performance traffic generator
- Taken over development and maintainership
- Has a Cisco-like CLI, but also a normal cmdline interface
- Intended for HW/SW applicance in your lab
- `mausezahn eth0 -A rand -B 1.1.1.1 -c 0 -t tcp "dp=1-1023, flags=syn" -P "Good morning! This is a SYN Flood Attack. We apologize for any inconvenience."`
- `mausezahn eth0 -M 214 -t tcp "dp=80" -P "HTTP..." -B myhost.com`

trafgen, mausezahn, pktgen

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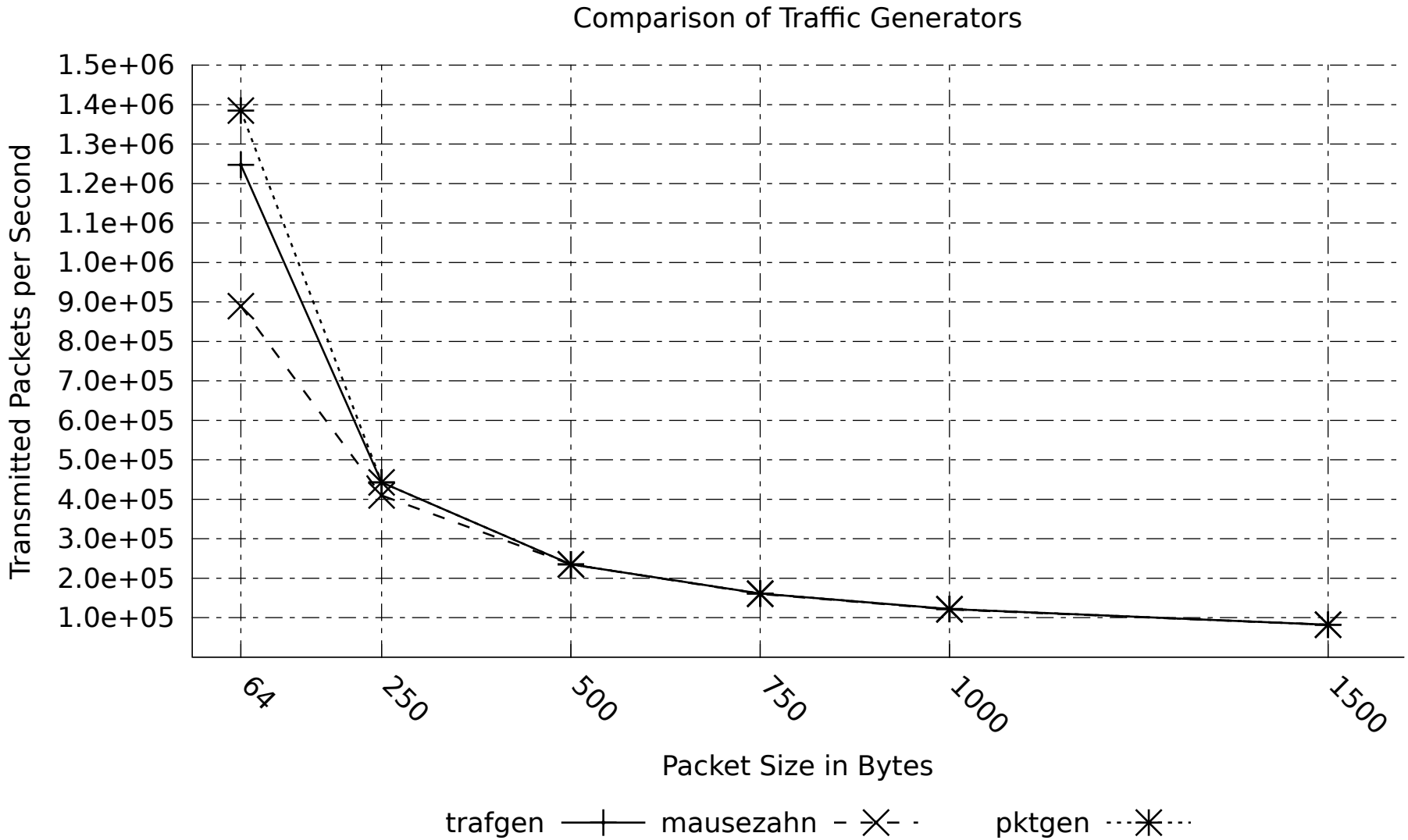

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What's next in netsniff-ng?

- The usual: cleanups, extend documentation, man-pages
- `bpf-hla`, high-level language for filtering
- DNS traceroute to detect malicious DNS injections on transit traffic
- Compressed on-the-fly bitmap indexing for large PCAP files
- New protocol dissectors/generators for netsniff-ng/mausezahn
- Further performance optimizations (OProfile is your friend)
- Hack `net/packet/af_packet.c` for a better performance

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Source Code

- Toolkit released under GPLv2.0
- Website: `http://www.netsniff-ng.org/`
- Github: `https://github.com/gnumaniacs/netsniff-ng`
- Patches, feedback are welcomed!