Efficient Implementation of Dynamic Protocol Stacks

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ABSTRACT

Network programming is widely understood as programming strictly defined socket interfaces. Only some frameworks (e.g., ANA, Click, Active Networking) have made a step towards *real* network programming by decomposing networking functionality into small modular blocks that can be assembled in a flexible manner. In this paper, we tackle the challenge of accommodating 3 partially conflicting objectives: (i) high flexibility for network programmers and network application designers, (ii) re-configuration of the network stack at runtime, and (iii) high packet forwarding rates. First experiences with a prototype implementation in Linux suggest little performance overhead compared to the standard Linux protocol stack.

1. INTRODUCTION

Beyond doubt, the Internet has grown out of its infancy. A huge variety of networked applications and a diverse range of protocols are available, ranging from protocols for the communication over fibre, cat5 or over the air to protocols supporting specific applications such as p2p, web or voIP. However, the architecture is not designed to also allow for an easy integration of new protocols between these two layers. We argue that an architecture that would not limit innovation to the outer layers would give the Internet another boost. Additionally, nowadays protocol stacks assume that the timely variances in a communication channel can be covered by adaptive parameters inside a single protocol. However, this might not be true for long lasting communications (e.g. in sensor networks). Network characteristics, privacy or security concerns might change with time. The protocol stack should be able to accommodate for such changes without the need for restarting the applications.

Some research addressing these goals was already done in active networking [3], with the Click modular router [4] or with openflow [5]. However, none of the available implementations fulfils the following three partially conflicting goals.

1. Simple integration and testing of new protocols on end nodes on all layers of the protocol stack.
2. Runtime reconfiguration of the protocol stack in order to allow for even bigger flexibility.
3. High performance packet forwarding rate.

Therefore, we propose another architecture that was designed with these objectives in mind. The architecture is based on the ideas of the *Autonomic Network Architecture (ANA).* [2]. In ANA network functionality is divided into *functional blocks (FB)* that can be combined as required. Each FB implements a protocol such as *ip, udp, encryption, content centric routing, etc.* ANA does not impose any protocols to be used other than Ethernet, rather it provides a framework that allows for the flexible composition and recomposition of FBs to a protocol stack. This allows for the experimentation with protocol stacks that are not known by todays standard operating system and it allows for the optimization of protocol stacks at runtime without communication tear down or application support. The existing implementation of ANA shows the feasibility of such a flexible architecture but it suffers sever performance issues. In this paper we present the *Lightweight Autonomic Network Architecture (LANA).* It allows for a similar functionality than ANA but demonstrates that flexibility does not have to come at the cost of reduced performance.

2. LANA

Generally, the LANA network system is built similarly to the network subsystem of the Linux kernel. Applications can send and transmit packets via the BSD socket interface. The actual packet processing is done in a *packet processing engine (PPE)* in the kernel space. An overview of the architecture is presented in (Figure 1).

The hardware and device driver interfaces are hidden from the PPE behind a *virtual link interface*, which allows for a simple integration of different underlaying networking technologies such as Ethernet, Bluetooth or InfiniBand.

Each functional block is implemented as a Linux kernel module. Upon module insertion a constructor for the creation of an instance of the FB is registered with the LANA core. Upon configuration of the protocol stack the instances of the FBs are created. The instances register a *receive function* with the PPE. This function is called when a packet needs to be processed.

Functional blocks can either drop a packet, forward a packet to either ingress or egress direction or duplicate a packet. After having processed a packet the FB returns the identifier of the next FB that should process this packet. In addition, FB belonging to the virtual link interface will

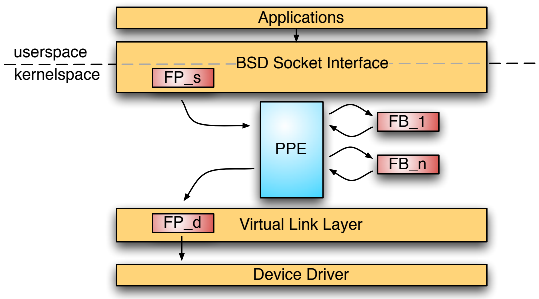

Figure 1: Packet flow in LANA

queue the packets in the network drivers transmit queue and FB communicating with BSD sockets will queue the packets in the sockets receive queue.

The PPE is responsible for calling one FB after the other and for queuing packets that need to be processed.

2.1 Configuration Interface

The protocol stack can be configured from user space with the help of a command line tool. The most important commands are summarized below.

- `add`, `rm`: Adds (removes) an FB from the list of available FBs in the kernel.
- `set`: sets properties of an FB with a `key=value` semantic
- `bind`, `unbind`: Binds (unbinds) an FB to another FB in order to be able to send messages to it.
- `replace`: Replaces one FB with another FB. The connections between the blocks are maintained. Private data can either be transferred to the new block or dropped.

Within the Linux kernel the notification chain framework is used to propagate those configuration messages to the individual FBs.

2.2 Improving the Performance

We have evaluated different possibilities for the integration of the PPE with the Linux kernel. We summarize our insights to provide guidance for researchers that have to do fundamental changes on the Linux protocol stack.

We compared the maximum packet reception rate of the Linux kernel while not doing any packet processing with our architecture. Here, packets are forwarded between three FBs that do only packet forwarding.

- One high priority LANA thread per CPU achieves approx. half the performance of the default stack. The performance degradation is due to 'starvation' of the software interrupt handler (ksoftirqd). Changing the priority of the LANA thread only slightly increases the throughput.
- Explicit preemption and scheduling control achieves approx. two third of the performance of the default stack. The performance degradation is due to scheduling overhead.
- Execution of the PPE in ksoftirqd context. This approach achieves approx. 95% of the performance of default stack.

The corresponding numbers are listed in Table 1.

Mechanism	Performance
Dedicated kernel thread (high priority)	700.000
Dedicated kernel thread (normal priority)	750.000
Dedicated kernel thread (controlled scheduling)	900.000
Execution in ksoftirqd	1.300.000
Linux kernel networking stack	1.380.000

Table 1: Performance evaluation in pps with 64 Byte packets. (Intel Core 2 Quad Q6600 with 2.40GHz, 4GB RAM, Intel 82566DC-2 NIC, Linux 3.0rc1)

2.3 Software Available

The current software is available under the GNU General Public License from [1]. In addition to the framework it also includes four functional blocks: Ethernet, Berkeley Packet Filter, Tee (duplication of packets), Packet Counter and Forward (an empty block that forwards the packets to another block). The framework does not need any patching of the Linux kernel but it requires a new Linux 3.X kernel.

3. CONCLUSIONS AND FUTURE WORK

We have shown that it is possible to implement a flexible protocol stack that has a similar performance than the default protocol stack in the Linux kernel. The flexibility allows for the easy inclusion of new, still to be developed protocols and for the change of the protocol stack at runtime. Both might lead to a protocol stack that is better suited for a given networking situation than the well known TCP/IP protocol stack.

In the short-term we will compare the performance of our system with the performance of other systems (e.g., default Linux stack, Click router, etc.). In the mid-term we will work on mechanisms that automatically configure protocol stacks based on the applications as well as the networks needs. The end goal is have a networked system that requires less configuration as compared to todays networks and that is able to adapt itself to changing network conditions.

4. ACKNOWLEDGMENTS

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