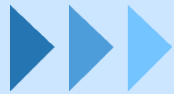


# ToMaTo

## *Topology Management Tool*

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<http://www.icsy.de>



# Introduction

*ToMaTo is a topology-oriented control framework for virtual networking experiments.*

## ▶ **Control framework**

- Like Planet-Lab, Emulab, ...
- Developed in the German-Lab project
- Open-Source project ([hosted on Github](#))

## ▶ **Virtual networking experiments**

- Developed for networking experiments
- E.g. networking research or software testing
- All parts of the experiment setup are virtual

## ▶ **Topology-oriented**

- Basic abstraction: Network topology
- Each experiment has its own topology
- Topologies contain connected elements

## ▶ **Advanced features**

- Direct console access
- Link emulation
- Packet capturing

# Topology

## ▶ Graphical representation

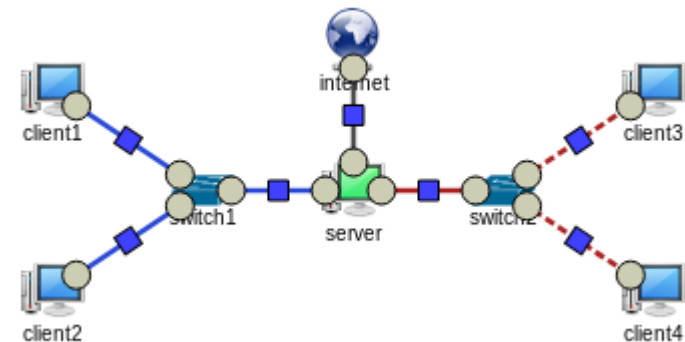
- Icons show element type
- Colored icons show virtualization technology
- Link color shows network segments
- Link style shows link attributes

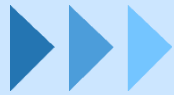
## ▶ Example

- One central server
- 4 clients, connected with 2 switches
- Internet connected to server

## ▶ Per Topology

- Accounting
- Permissions





- ▶ **KVM**
  - Full virtualization
  - Integrated into Linux Kernel
  
- ▶ **OpenVZ**
  - Container virtualization
  - Added to Linux Kernel via patch
  
- ▶ **Scripts**
  - Programming language virtualization
  - Installed as software
  
- ▶ **Additional elements**
  - Easy to add more
  - Planned: VirtualBox, LXC

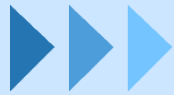
## ▶ Repy

- Restricted Python (Sandbox)
- Technology from Seattle testbed
- Modified for ToMaTo
- Functions for receiving and sending raw ethernet packages

```
packet = tuntap_read("eth0", timeout=None)
ethernet = ethernet_decode(packet)
echo("%s -> %s: %d bytes\n" % (ethernet.src, ethernet.dst, len(packet)))
tuntap_send("eth1", packet)
```

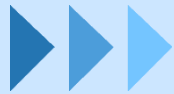
## ▶ Library

- Basic protocols implemented: Ethernet, IPv4, TCP, UDP and ICMP
- Even some higher protocols: DHCP and DNS
- Examples for: NAT router, DHCP server, DNS server, Switch, ...
- Can be extended within the language



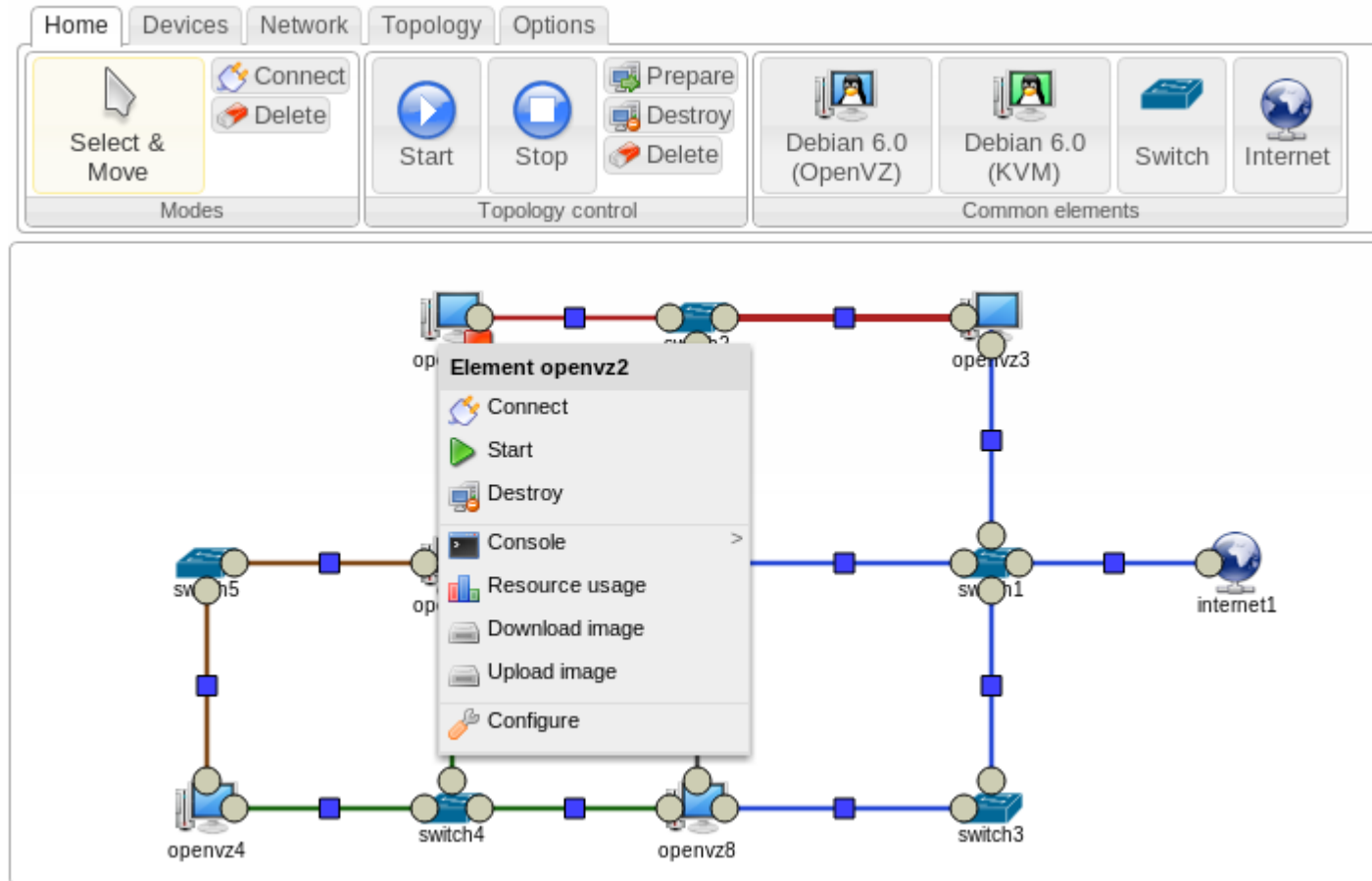
# VM Elements - Features

	KVM	OpenVZ	Repy scripts
# per node	~20	~100	~1000
any x86 OS	✓	✗	✗
Linux OS	✓	✓	✗
Kernel space	✓	✗	(✓)
Console support	✓	✓	✓
Mouse/Keyboard input	✓	✓	✗
Layer 2 connectivity	✓	✓	✓
Interface configuration	(✓)	✓	(✓)



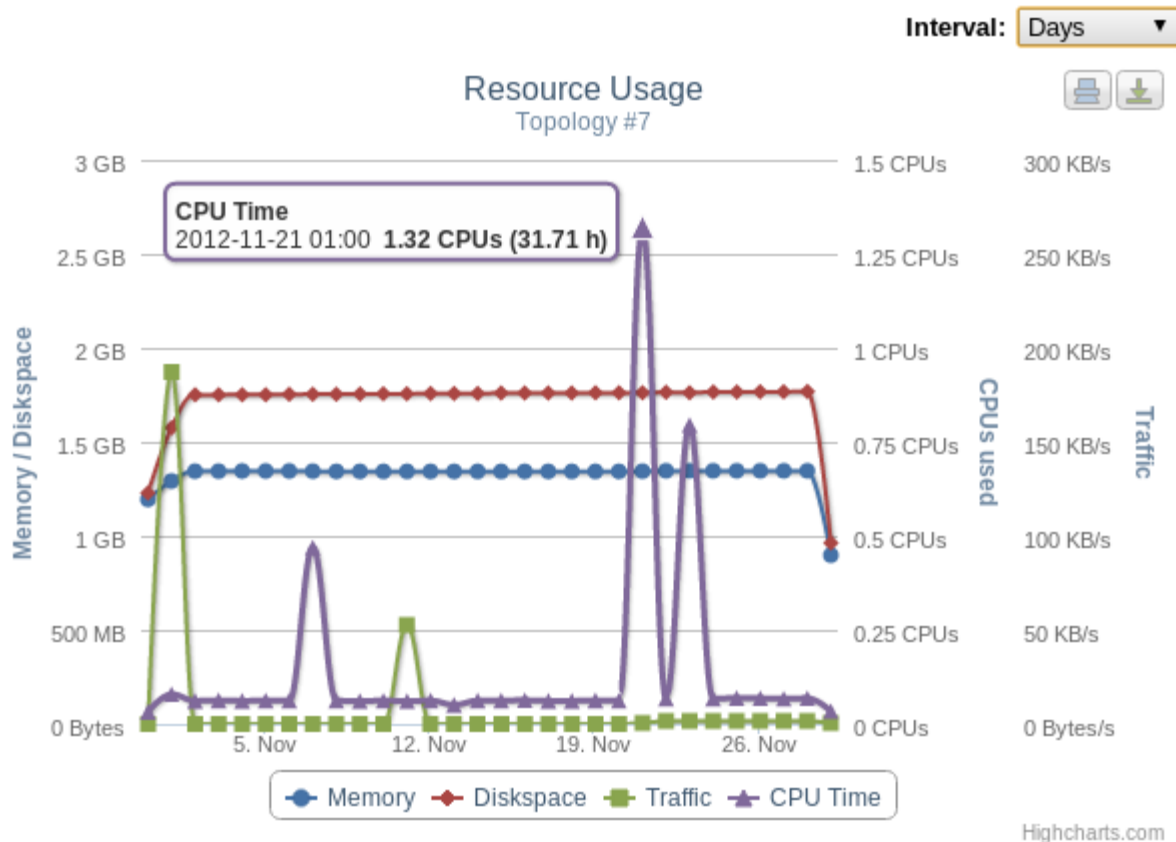
- ▶ **VPN: Tinc**
  - Full mesh VPN without server
  - Fully contained, virtual network
  - Cross-site layer 2 connectivity
  - Open endpoints allow federation
  
- ▶ **Tunnel: VTun**
  - Layer 2 tunnel over UDP
  - Open endpoints allow federation
  
- ▶ **External networks**
  - Bridge into local network segments
  - E.g. Internet or local research network

# Webfrontend - Editor





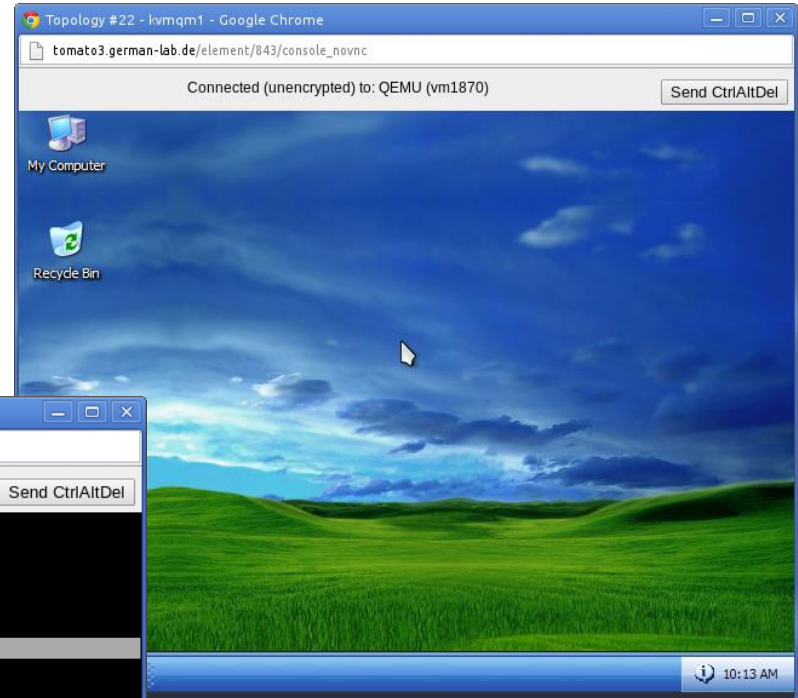
# Webfrontend – Usage Statistics



# Console Access

## Multiple VNC options

- HTML 5
- Java applet
- Client software



Topology #22 - computer1 - Google Chrome  
tomato3.german-lab.de/element/827/console\_novnc  
Connected (unencrypted) to: VNC Command Terminal Send CtrlAltDel

```
top - 11:16:52 up 0 min, 0 users, load average: 0.05, 0.01, 0.00
Tasks: 9 total, 1 running, 8 sleeping, 0 stopped, 0 zombie
Cpu(s): 0.0%us, 0.0%sy, 0.0%ni,100.0%id, 0.0%wa, 0.0%hi, 0.0%si, 0.0%st
Mem: 524288k total, 9780k used, 514508k free, 0k buffers
Swap: 524288k total, 0k used, 524288k free, 6768k cached
```

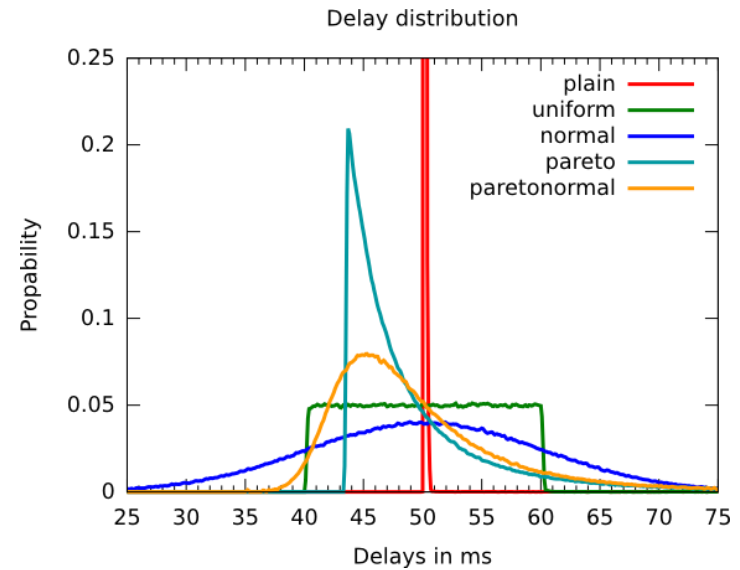
PID	USER	PR	NI	UIRT	RES	SHR	S	%CPU	%MEM	TIME+	COMMAND
1	root	20	0	2028	696	600	S	0.0	0.1	0:00.00	init
2	root	20	0	0	0	0	S	0.0	0.0	0:00.00	kthreadd/1436
3	root	20	0	0	0	0	S	0.0	0.0	0:00.00	khelper/1436
14	root	20	0	104	12	4	S	0.0	0.0	0:00.00	init-logger
205	root	20	0	27280	1340	972	S	0.0	0.3	0:00.00	rsyslogd
231	root	20	0	3780	772	604	S	0.0	0.1	0:00.00	cron
248	root	20	0	18648	624	440	S	0.0	0.1	0:00.00	vzctl
249	root	20	0	4480	1724	1404	S	0.0	0.3	0:00.00	bash
258	root	20	0	2328	1080	892	R	0.0	0.2	0:00.00	top

10:13 AM

# Link Emulation

## ▶ Properties

- Bandwidth
- Latency
- Jitter
- Packet loss
- Corruption & duplication



### Link emulation

Enabled	<input checked="" type="checkbox"/>		
Direction	From openvz1.eth0 to tinc_vpn5.tinc_endpoint6	From tinc_vpn5.tinc_endpoint6 to openvz1.eth0	
Bandwidth	<input type="text" value="10000"/>	<input type="text" value="10000"/>	kbit/s
Delay	<input type="text" value="0"/>	<input type="text" value="0"/>	ms
Jitter	<input type="text" value="0"/>	<input type="text" value="0"/>	ms
Distribution	<input type="text" value="Uniform"/>	<input type="text" value="Uniform"/>	
Loss ratio	<input type="text" value="0"/>	<input type="text" value="0"/>	%
Duplication ratio	<input type="text" value="0"/>	<input type="text" value="0"/>	%
Corruption ratio	<input type="text" value="0"/>	<input type="text" value="0"/>	%

# Packet Capturing

## ▶ Properties

- Captures packages on the wire
- Direct filtering
- Format: Pcap, (compatible with Wireshark)
- Two modes: Download, Live capture

### Packet capturing

Enabled

Capture mode

For download ▼

Packet filter expression

## ▶ Cloudshark

- Online tool for packet analysis

Current File: <http://blog.rootshell.be/wp-content/uploads/2010/06/cloudsharkdemo.pcap> download original (1.1 kb)

CloudShark

No.	Time	Source	Destination	Protocol	Info
1	0.000000	192.168.254.229	88.191.119.130	ICMP	Echo (ping) request
2	0.054183	88.191.119.130	192.168.254.229	ICMP	Echo (ping) reply
3	1.001388	192.168.254.229	88.191.119.130	ICMP	Echo (ping) request
4	1.054820	88.191.119.130	192.168.254.229	ICMP	Echo (ping) reply
5	2.002870	192.168.254.229	88.191.119.130	ICMP	Echo (ping) request
6	2.056771	88.191.119.130	192.168.254.229	ICMP	Echo (ping) reply
7	3.004017	192.168.254.229	88.191.119.130	ICMP	Echo (ping) request
8	3.058191	88.191.119.130	192.168.254.229	ICMP	Echo (ping) reply
9	4.005573	192.168.254.229	88.191.119.130	ICMP	Echo (ping) request
10	4.059409	88.191.119.130	192.168.254.229	ICMP	Echo (ping) reply

▶ Frame 1 (98 bytes on wire, 98 bytes captured)

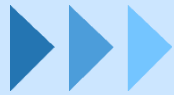
▶ Ethernet II, Src: Dell\_ad:4d:aa (00:21:70:ad:4d:aa), Dst: 3Com\_17:0c:77 (00:04:76:17:0c:77)

▶ Internet Protocol, Src: 192.168.254.229 (192.168.254.229), Dst: 88.191.119.130 (88.191.119.130)

▼ Internet Control Message Protocol

Type: 8 (Echo (ping) request)  
Code: 0 ()  
Checksum: 0x8bdc [correct]  
Identifier: 0x1524  
Sequence number: 1 (0x0001)  
Data: 274F224C00000006A8F04000000000101121314151617...  
Length: 56

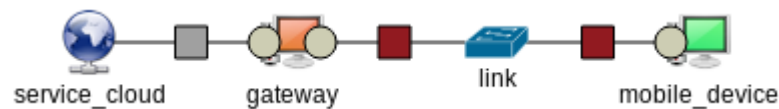
```
0000 00 04 76 17 0c 77 00 21 70 ad 4d aa 08 00 45 00  .v.v!p.M...E.
0010 00 54 00 00 40 00 40 01 aa d9 c0 a8 fe e5 58 bf  .T.e@.....X.
0020 77 82 00 00 00 00 00 00 00 00 00 00 00 00 00  w.
0030 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ]
0040 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ]
```



- ▶ **Hardware in German-Lab**
  - Strong nodes: 16 GB Ram, 2 Quad-Cores, 4 Gigabit LAN
  - 59 nodes in Kaiserslautern
  - 25 nodes in Würzburg, Darmstadt, Karlsruhe and Munich each
  
- ▶ **ToMaTo deployment**
  - 60 ToMaTo nodes in whole German-Lab
  - 6 ToMaTo nodes in GENI
  
- ▶ **Additional hardware and links**
  - Multiple OpenFlow switches connected to ToMaTo in Würzburg
  - Gigabit link to GENI connected to ToMaTo in Kaiserslautern
  
- ▶ **Other ToMaTo installations**
  - Used in Vietnam for research
  - Testing in China

## ► Scenario

- Services for agriculture
- Support for mobile devices
- How does latency affect QoE?



## ► ToMaTo usage

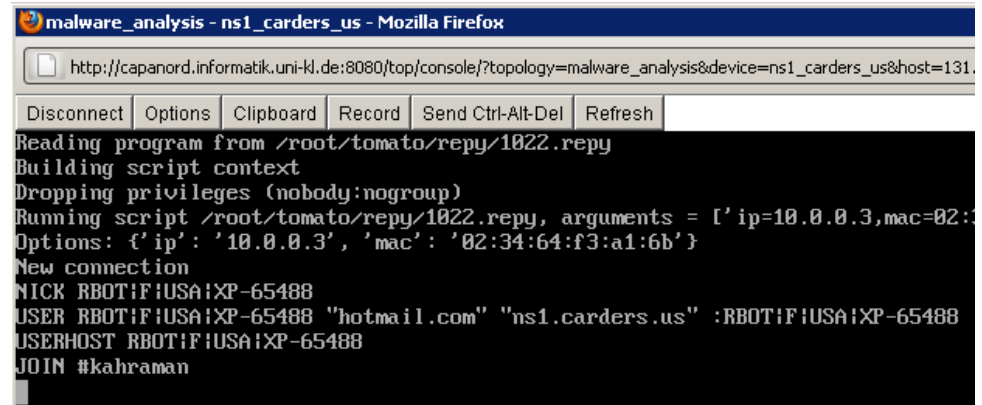
- Simple topology
- Special template with Android emulator
- Usage of link emulation



# Use case: Malware Analysis

## ► Scenario

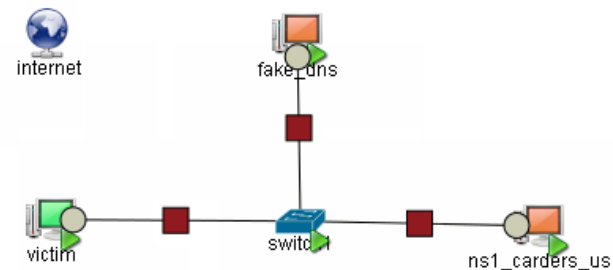
- Analysis of worm
- Focus on network behavior
- Fully contained topology

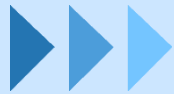


```
malware_analysis - ns1_cadders_us - Mozilla Firefox
http://capanord.informatik.uni-kl.de:8080/top/console/?topology=malware_analysis&device=ns1_cadders_us&host=131.
Disconnect Options Clipboard Record Send Ctrl-Alt-Del Refresh
Reading program from /root/tomato/repy/1022.repy
Building script context
Dropping privileges (nobody:nogroup)
Running script /root/tomato/repy/1022.repy, arguments = ['ip=10.0.0.3,mac=02:34:64:f3:a1:6b']
Options: {'ip': '10.0.0.3', 'mac': '02:34:64:f3:a1:6b'}
New connection
NICK RBOT!F!USA!XP-65488
USER RBOT!F!USA!XP-65488 "hotmail.com" "ns1.cadders.us" :RBOT!F!USA!XP-65488
USERHOST RBOT!F!USA!XP-65488
JOIN #kahraman
```

## ► ToMaTo usage

- Simple topology
- No connection to Internet
- Usage of packet capturing

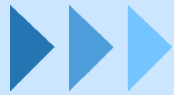




# Framework Comparison

	Planet-Lab	Emulab	Seattle	ToMaTo
Multiple sites	✓	✗	(✓)	✓
Physical hardware access	✗	✓	✗	✗
End-System virtualization	✓	(✓)	✓	✓
Network virtualization	✗	✓	✗	✓
Layer 2 access	✗	✓	✗	✓
Link emulation	✗	✓	✗	✓
Packet capturing	✗	(✓)	✗	✓
High traffic (>100 Mbit/s)	✗	✓	✗	✗
Resource profiles	✓	✗	✗	✓
VNC control	✗	✗	✗	✓





## ▶ **Versions**

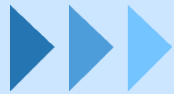
- Version 2.5 (mid 2012)
- Version 3.0 (April 2013, still hunting some bugs)

## ▶ **Planned element types & features**

- Local virtual networks via VLAN technology
- Better support for OpenFlow network elements
- Other virtualization technologies (Virtualbox, LXC)
- Support for OpenStack (external work)

## ▶ **Planned cooperation**

- Forming an international community
- International outposts
- Bridges into major research networks



## ► Websites

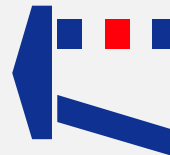
- ToMaTo project: <http://dswd.github.com/ToMaTo>
- ToMaTo German-Lab testbed: <http://tomato3.german-lab.de>
- German-Lab: <http://ww.german-lab.de>

## ► Publications

- ToMaTo - a network experimentation tool  
*Dennis Schwerdel, David Hock, Daniel Günther, Bernd Reuther, Paul Müller and Phuoc Tran-Gia*  
7th International ICST Conference on Testbeds and Research Infrastructures for the Development of Networks and Communities (TridentCom 2011), Shanghai, China, April 2011.
- Future Internet Research and Experimentation: The G-Lab Approach  
*Dennis Schwerdel, Bernd Reuther, Thomas Zinner, Paul Müller and Phuoc Tran-Gia*  
Computer Networks, special issue on FI testbeds, tbp



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