

# Experience teaching seL4 seL4 Summit 2022

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# Agenda

- Course Overview
- Theoretical Phase (lecture units)
- TRENTOS
- Practical Phase (coding units)
  - Homework Assignments
  - Team Projects
- Results
- Future Work

# Course Overview

- Since winter term 2020 @TUM
- Participants: max. 15 students per term
- Group work: team size of max. 3 students
- Focus: L4 microkernel development in the area of embedded systems
  - Development of embedded systems
  - Better understanding of components utilized in modern (microkernel) OS
  - OS development based on seL4, CAMkES and TRENTOS
- Structure: from theory to practice
  - Theoretical Part: several lecture units, concerning hardware/bootloader, seL4, CAMkES and TRENTOS
  - Practical Part
    - Hands-on training: homework assignments
    - Team projects focusing on real-world application

# Theoretical Phase

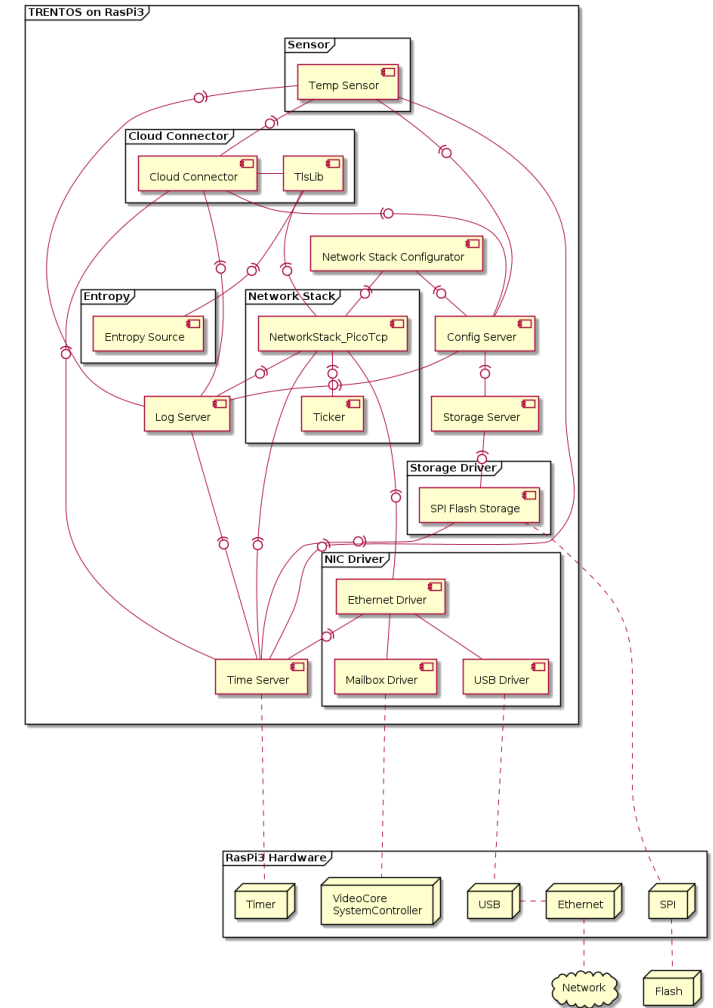
- Embedded Hardware
  - ARM/RISC-V
  - SoC, SBC
  - bootloader
- Kernel: seL4
  - microkernel vs. monolithic kernel
  - L4 history
  - seL4 building blocks (kernel objects, capabilities)
  - formal verification
- CAmkES
  - componentised systems
  - building blocks

# Theoretical Phase ctd.

- TRENTOS
  - architecture
  - SDK structure
  - build and test environment
  - building blocks
  - how to write your own TRENTOS application
- TRENTOS Development Kit
  - TRENTOS SDK
  - Raspberry Pi 3 B+ based hardware environment
  - selected peripherals and cabling

# TRENTOS – Overview

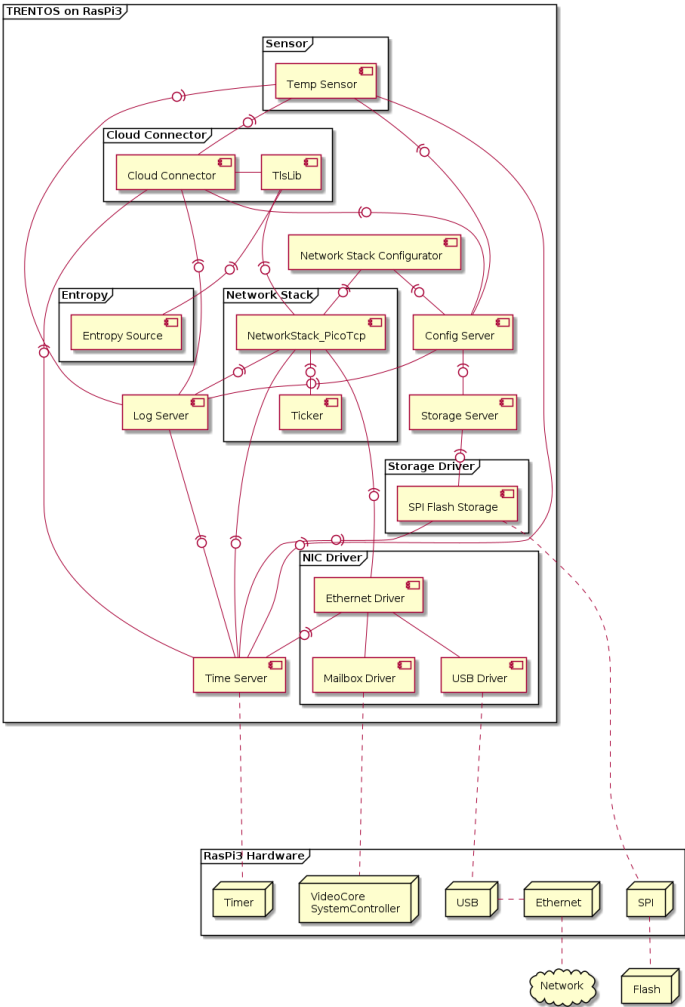
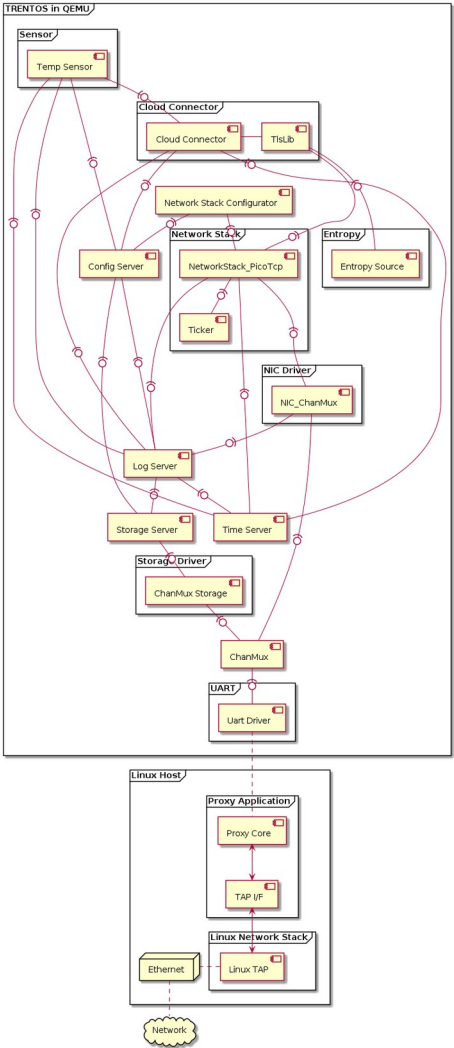
- A novel secure embedded operating system developed by HENSOLDT Cyber
- Built on top of the seL4 microkernel and the CAMkES framework
- Focused on creating static systems
  - No dynamic reconfiguration (CAMkES)
  - Highly dynamic systems only via virtualization
  - No focus on GUI frameworks
- Ready-to-use components (drivers, middleware, ...)
- Standardized, platform-agnostic interfaces
- Support for both ARM and RISC-V
- Suited for formal verification (CAMkES toolchain)



# TRENTOS – SDK Structure

- **GettingStarted.pdf** → Link to `sdk/doc/pdf/TRENTOS_GettingStarted_SDK_V1.3.pdf`
- **docker** → Containers with toolchain to build and test TRENTOS systems
  - `trentos_1.3.sha256sums`
  - `trentos_build_20210503.bz2`
  - `trentos_test_20211025.bz2`
- **sdk**
  - `build-system.sh` → Master build script for building TRENTOS systems
  - `CMakeLists.txt` → Master CMake script for building TRENTOS systems
  - `README.license` → License information
  - `bin` → TRENTOS tools binaries for Linux
    - `cpt` → Configuration Provisioning Tool
    - `proxy_app` → Proxy Application
    - `rdgen` → RamDisk Generator
  - `components` → TRENTOS components sources
    - `CertServer` → Component to offer "read access" to the set of trusted certificates (the "trusted chain")
    - `ChanMux` → Channel Multiplexer component for communication with the Proxy Application
    - `CryptoServer` → CryptoServer+Keystore component
    - `EntropySource` → Dummy TRNG driver
    - `NetworkStack_PicoTcp` → Network stack component based on picoTCP
    - `NIC_ChanMux` → Network driver for a ChanMux NIC channel
    - `NIC_Dummy` → Dummy network driver
    - `NIC_iMX6` → Network driver for the iMX6 platform
    - `NIC_RPi` → Network driver for RPi3B+
    - `RamDisk` → RAM-based storage driver
    - `RPi_SPI_Flash` → Storage driver for SPI-based NOR flash memory for RPi3B+
    - `SdHostController` → Driver that implements the storage interface and allows accessing the SD card peripheral
    - `Storage_ChanMux` → Storage driver for a ChanMux storage channel
    - `StorageServer` → Providing access to storage for various clients
    - `TimeServer` → Providing access to timers for various clients
    - `TlsServer` → TLS client + networking component
    - `UART` → UART driver
  - `denos`
    - `deno_hello_world` → Hello World demo
    - `deno_iot_app` → IoT Demo (QEMU)
    - `deno_iot_app_imx6` → IoT Demo (Nitrogen6\_SoloX, BD-SL-i.MX6)
    - `deno_iot_app_rpi3` → IoT Demo (RPi3B+)
    - `deno_network_filter` → Network Filter Demo (QEMU, Nitrogen6\_SoloX)
    - `deno_tls_api` → Demo retrieving an HTTPS web page
- **doc**
  - `html` → TRENTOS API Doxygen documentation
  - `pdf` → TRENTOS documentation
    - `TRENTOS_GettingStarted_SDK_V1.3.pdf`
    - `TRENTOS_Handbook_SDK_V1.3.pdf`
    - `TRENTOS_ReleaseNotes_SDK_V1.3.pdf`
    - `TRENTOS_MigrationNotes_SDK_V1.2_to_V1.3.pdf`
    - `3rd_party` → Supplemental documents
- **libs** → TRENTOS libraries and core system sources
  - `3rdParty` → 3rd party libraries used by TRENTOS libraries internally
  - `chanmux` → ChanMux
  - `chanmux_nic_driver` → Network driver based on ChanMux
  - `lib_compiler` → Compiler abstraction utilities
  - `lib_debug` → Debugging facility macros and functions
  - `lib_host` → Host side utilities
  - `lib_io` → I/O operations
  - `lib_logs` → Logging utilities
  - `lib_macros` → Commonly used macros
  - `lib_mem` → Memory management utilities
  - `lib_osal` → Operating System abstraction library
  - `lib_server` → Server components utilities
  - `lib_utils` → Common useful utilities
  - `os_cert` → Certification parser library for x509 certificates
  - `os_configuration` → Configuration server library
  - `os_crypto` → Crypto library
  - `os_filesystem` → File system library (FAT, SPIFFS, LittleFS)
  - `os_keystore` → Keystore library (file based, RAM based)
  - `os_logger` → Log server core library
  - `os_socket` → Socket library
  - `os_tls` → TLS client library
  - `os_core_api` → TRENTOS APIs for all subsystems
- **resources**
  - `nitrogen6sx_sd_card` → SD card files with Nitrogen6\_SoloX bootloader
  - `openocd_cfgs` → Configuration files for debugging with OpenOCD
  - `rpi3_sd_card` → SD card files with RPi3B+ bootloader
  - `sabre_sd_card` → SD card files with BD-SL-i.MX6 bootloader
- **scripts** → Utility scripts
- `sdk-seL4-cankes` → seL4 and CAMKES
- **tools** → TRENTOS tools source code
  - `cpt` → Configuration Provisioning Tool
  - `proxy` → Proxy Application
  - `rdgen` → RamDisk Generator
  - `rpi3_flasher` → TRENTOS helper system for flashing an image on the RPi3B+ SPI-based NOR flash memory

# TRENTOS – Componentised Setup





# TRENTOS – How to use

```
StorageServer_DeclareCAmkESComponent(
    StorageServer
)

DeclareCAmkESComponent(
    TestApp
    SOURCES
        components/TestApp/src/TestApp.c
    C_FLAGS
        -Wall
        -Werror
    LIBS
        system_config
        lib_debug
        os_core_api
        os_filesystem
)
```

```
import <std_connector.camkes>;

#include "system_config.h"

//-----
// Storage
//-----

#include "RamDisk/RamDisk.camkes"
RamDisk_COMPONENT_DEFINE(RamDisk)

#include "StorageServer/camkes/StorageServer.camkes"
StorageServer_COMPONENT_DEFINE(StorageServer)

import "components/TestApp/TestApp.camkes";

//-----
// System
//-----

assembly {
    composition {
        //-----
        // Storage
        //-----
        component RamDisk ramDisk;

        //-----
        // StorageServer
        //-----
        component StorageServer storageServer;

        StorageServer_INSTANCE_CONNECT(
            storageServer,
            ramDisk.storage_rpc, ramDisk.storage_port
        )

        StorageServer_INSTANCE_CONNECT_CLIENTS(
            storageServer,
            testApp.storage_rpc_1, testApp.storage_dp_1,
            testApp.storage_rpc_2, testApp.storage_dp_2
        )
    }
}
```

# TRENTOS – Create your own application

- Each application consists of
  - Build/test specific parts (*CMakeLists.txt*, *run\_demo.sh*)
  - A central CAMkES application description (main *.camkes* file), which is used for declaration and instantiation of all required components and connections
    - re-using TRENTOS standard components (by utilizing specific macros)
    - creating own components (e.g. making use of the TRENTOS API)
  - A folder „components“ which contains a folder for each own component offering
    - a *.camkes* component description + optional interface definitions
    - own logic in C code + usage of TRENTOS API
  - Optional: a global configuration (*system\_config.h*)

# TRENTOS – Evaluation Kit



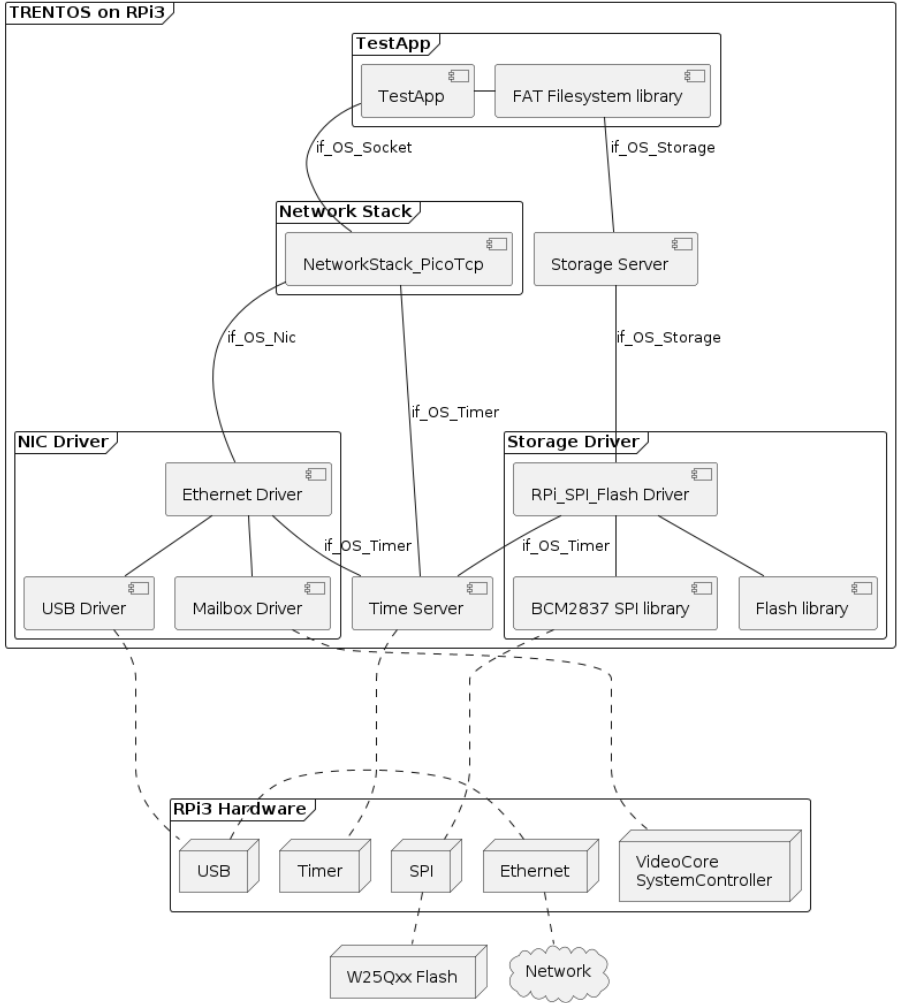
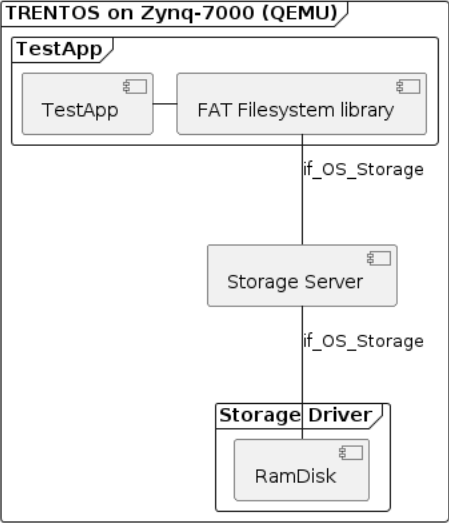
# Practical Phase

- Homework Assignments (each participant)
  - Based on the OS tutorials presented/explained in the course
  - Small project, iteratively developing (e.g. starting with a simple storage application, which gets extended via networking capabilities)
- Team Projects (exemplarily from summer term 2022)
  - Simulator Case
    - Porting of a driver for a specific SPI/I2C-based peripheral
    - Development of a demo application for a simulator based automotive/robotics/drone setup
  - Security Case
    - Porting of a driver for a SPI-based TPM peripheral
    - Development of a demo application for a crypto/key store related use case, e.g. an encrypted file system

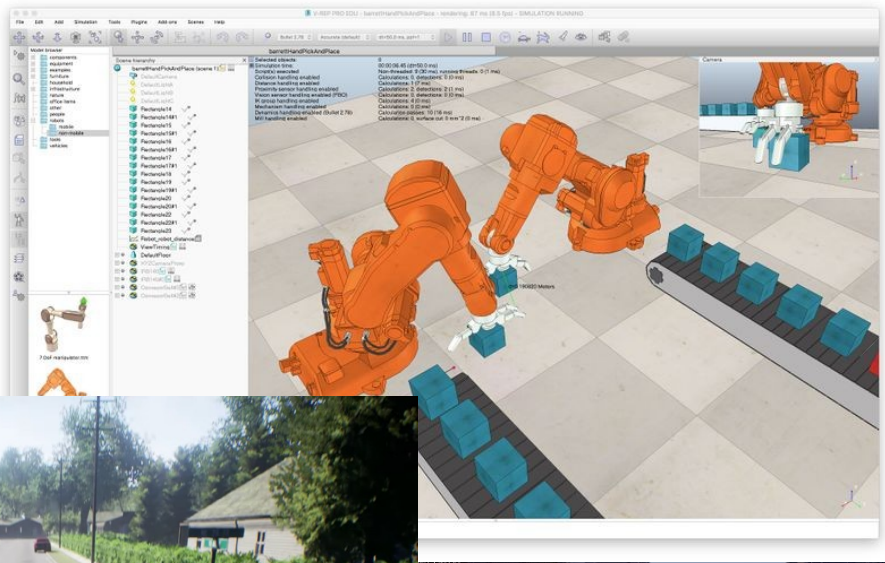
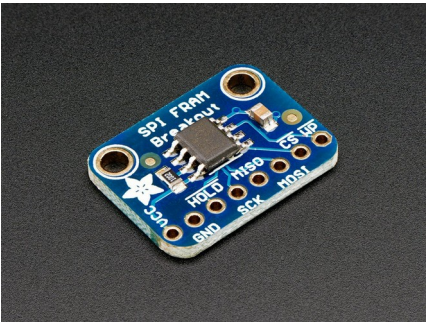
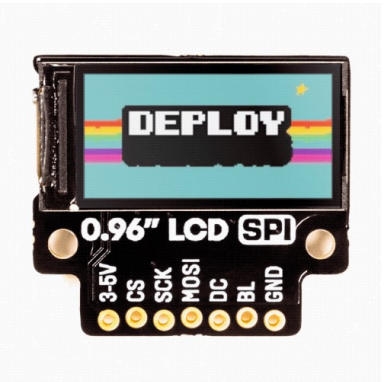
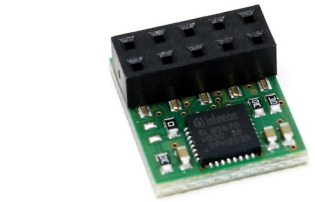
# Practical Phase – Homework Assignments

- Base Setup: QEMU-based setup, utilizing TRENTOs storage facilities (RamDisk) in combination with the TRENTOs FileSystem API on two partitions
- Task 1: Switch of file system type (from FAT to SPIFFS)
- Task 2: Switch from QEMU to Raspberry Pi 3 B+
- Task 3: Switch from RamDisk to SPI NOR flash memory
- Task 4: Extension via network facilities, using TRENTOs on the Raspberry Pi as server (receiving a String from a connected PC)
- Task 5: Transition of the network setup from server to client, allowing TRENTOs on the Raspberry Pi to get a small webpage from a webserver running on a connected PC

# Practical Phase – Homework Assignments



# Practical Phase – Team Projects: Utilized Environments



# Practical Phase – Example 1: Drone Simulator Setup

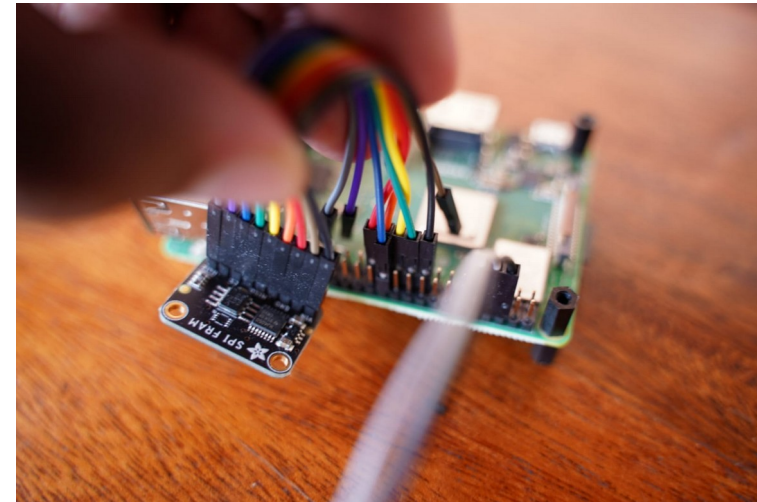
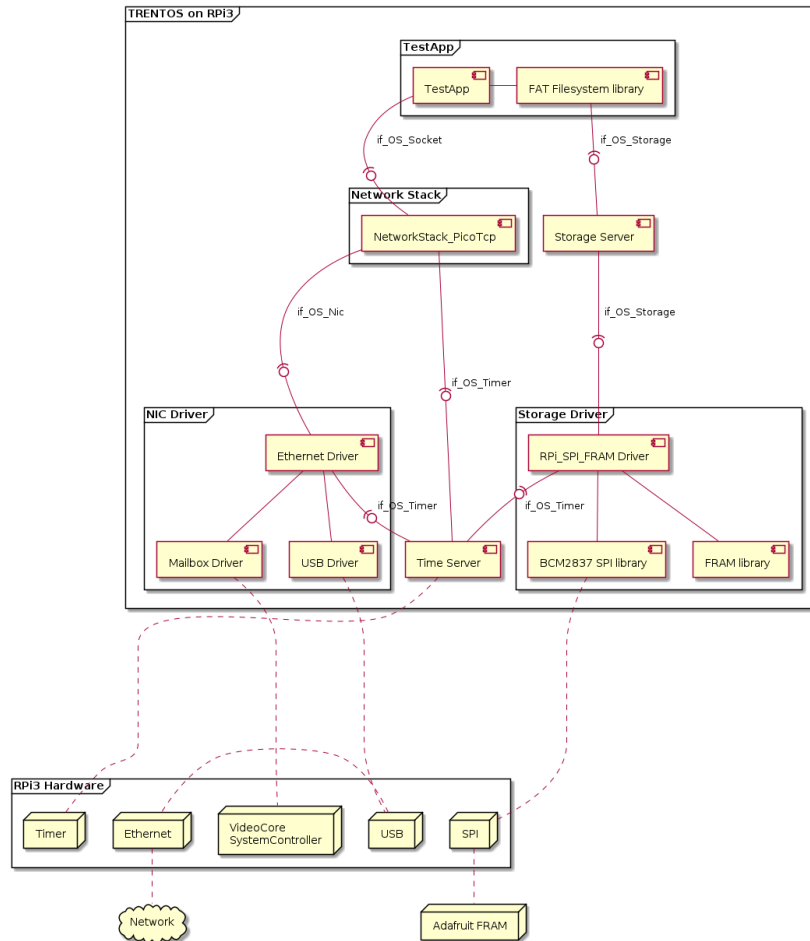
- Connection of a drone simulator (e.g. Microsoft AirSim) environment for controlling a virtual drone via TRENTO that
  - receives virtual sensor data (e.g. from a Lidar sensor)
  - calculates a flight path to the highest surrounding position
  - offers adequate flight controller logic for steering the drone by utilizing selected virtual actuators
- Implementation of a driver for an SPI-based FRAM breakout board in order to replace the existing SPI-based NOR flash memory
  - An Adafruit SPI FRAM breakout board is used exemplarily
  - An existing open-source driver/library shall be ported to TRENTO
- Implementation of a driver for an SPI-based Ethernet breakout board in order to replace the existing RPi 3 B+ internal network controller
  - A Microchip ENC28J60 SPI-based Ethernet controller is used exemplarily
  - An existing open-source driver/library shall be ported to TRENTO



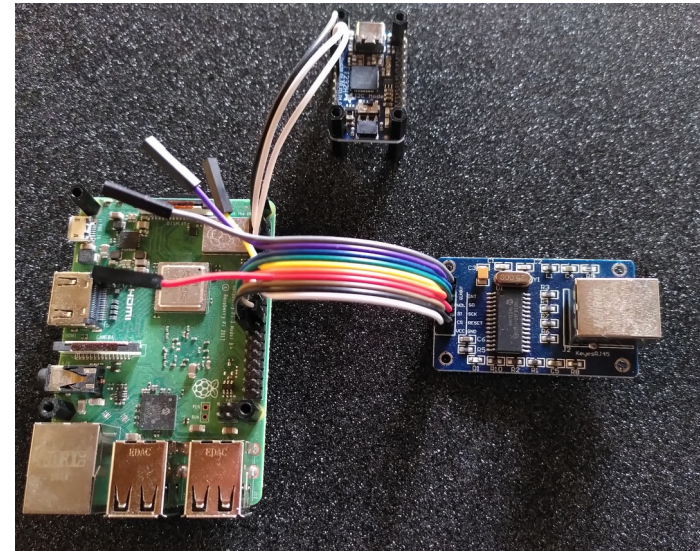
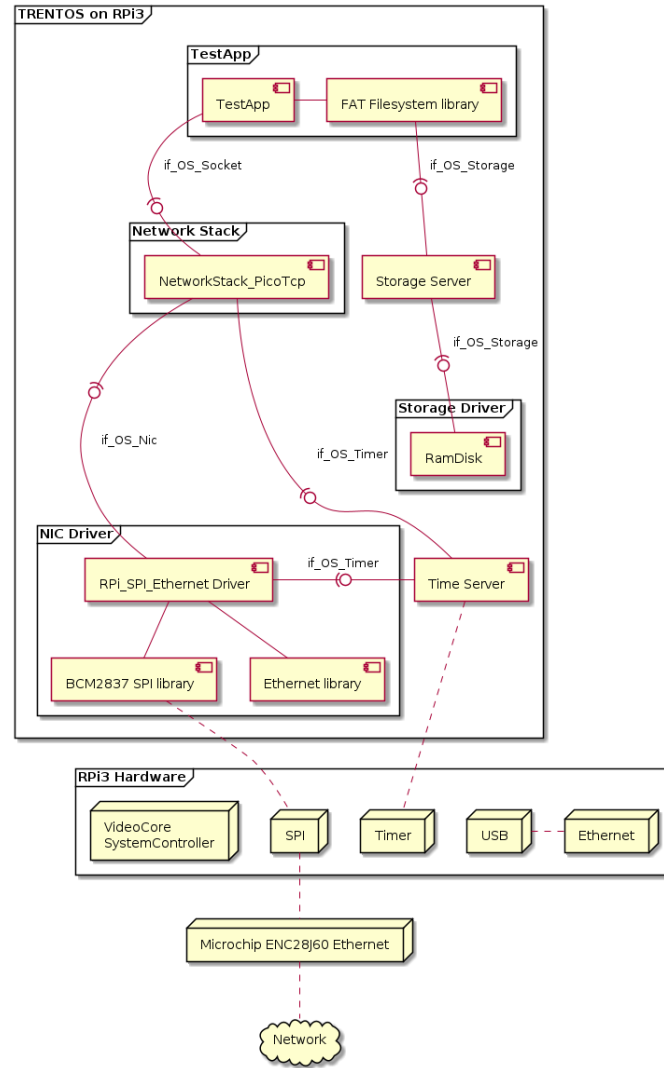
## Practical Phase – Example 2: TPM-based security

- Porting of a standardized open-source library for integrating an SPI-based TPM device (e.g. LetsTrust TPM) within TRENTOs to allow for
  - hardware-supported key store functionality
  - hardware-based acceleration of OS crypto functionality
- Development of encrypted file system functionality by using
  - the TPM as key store
  - selected software-based crypto algorithm(s) for encrypting/decrypting files/file content within the existing TRENTOs file system support
  - selected hardware-accelerated crypto algorithm(s) for encrypting/decrypting files/file content within the existing TRENTOs file system support
- Realization of performance measurements to allow for a comparison between both software-based and hardware-accelerated crypto functionality

# Practical Phase – Results: SPI FRAM



# Practical Phase – Results: SPI Ethernet



# Practical Phase – Results: Autonomous Driving Simulator

The image displays a top-down view of a simulated autonomous driving environment. Several cars are visible on a road, including a blue car, a red car, and a white car. The environment includes lane markings, a road sign, and a utility pole. On the left side, a terminal window shows system logs and network traffic. The logs include messages from the ROS (Robot Operating System) and the ADAS (Advanced Driver Assistance System) components, such as receiving datapoints, finding parking spots, and evaluating sensor data. The network traffic shows a series of ACK (Acknowledgment) packets between the simulator and a host, indicating successful data transmission.

```

INFO: /host/home/singimhale/repos/ws2021_team_3_ads/TestApp/components/TestApp/src/TestApp.c:188: Received Datapoint: time: 34.931, gnss
(130.171:8.452), dist: 5.169, v: (4.917:8.086)
INFO: /host/home/singimhale/repos/ws2021_team_3_ads/TestApp/components/TestApp/src/TestApp.c:188: Received Datapoint: time: 35.026, gnss
(130.035:8.463), dist: 5.168, v: (4.917:8.086)
INFO: /host/home/singimhale/repos/ws2021_team_3_ads/TestApp/components/TestApp/src/TestApp.c:188: Received Datapoint: time: 35.026, gnss
(130.035:8.463), dist: 5.168, v: (4.917:8.086)
INFO: /host/home/singimhale/repos/ws2021_team_3_ads/TestApp/components/TestApp/src/TestApp.c:188: Received Datapoint: time: 35.132, gnss
(131.164:8.472), dist: 5.166, v: (4.918:8.086)
INFO: /host/home/singimhale/repos/ws2021_team_3_ads/TestApp/components/TestApp/src/TestApp.c:188: Received Datapoint: time: 35.132, gnss
(131.164:8.472), dist: 5.166, v: (4.918:8.086)
INFO: /host/home/singimhale/repos/ws2021_team_3_ads/TestApp/components/TestApp/src/TestApp.c:188: Received Datapoint: time: 35.132, gnss
(131.164:8.472), dist: 5.166, v: (4.918:8.086)
INFO: /host/home/singimhale/repos/ws2021_team_3_ads/TestApp/components/TestApp/src/TestApp.c:188: Received Datapoint: time: 35.132, gnss
(131.164:8.472), dist: 5.166, v: (4.918:8.086)
INFO: /host/home/singimhale/repos/ws2021_team_3_ads/TestApp/components/TestApp/src/TestApp.c:188: Received Datapoint: time: 35.233, gnss
(111.661:8.481), dist: 5.164, v: (4.918:8.086)
INFO: /host/home/singimhale/repos/ws2021_team_3_ads/TestApp/components/TestApp/src/TestApp.c:188: Received Datapoint: time: 35.233, gnss
(111.661:8.481), dist: 5.164, v: (4.918:8.086)
INFO: /host/home/singimhale/repos/ws2021_team_3_ads/TestApp/components/TestApp/src/TestApp.c:188: Received Datapoint: time: 35.233, gnss
(111.661:8.481), dist: 5.164, v: (4.918:8.086)
INFO: /host/home/singimhale/repos/ws2021_team_3_ads/TestApp/components/TestApp/src/TestApp.c:188: Received Datapoint: time: 35.233, gnss
(111.661:8.481), dist: 5.164, v: (4.918:8.086)
INFO: /host/home/singimhale/repos/ws2021_team_3_ads/TestApp/components/TestApp/src/TestApp.c:188: Received Datapoint: time: 35.233, gnss
(111.661:8.481), dist: 5.164, v: (4.918:8.086)
INFO: /host/home/singimhale/repos/ws2021_team_3_ads/TestApp/components/TestApp/src/TestApp.c:128: Found valid parking spot for vehicle
stopping car.
INFO: /host/home/singimhale/repos/trentos/sdk/components/NetworkStack_PicoTcp/src/network_stack_pico.c:494: [socket 0x0192cc] socket c
losed
INFO: /host/home/singimhale/repos/ws2021_team_3_ads/TestApp/components/TestApp/src/TestApp.c:42: 0 - parking_spot: start: x: 74.825492
y: 7.823781 | end: x: 78.246878 | y: 7.899828 | length: 4.348888
INFO: /host/home/singimhale/repos/ws2021_team_3_ads/TestApp/components/TestApp/src/TestApp.c:42: 1 - parking_spot: start: x: 83.687813
y: 7.992482 | end: x: 86.127182 | y: 8.034996 | length: 2.439741
INFO: /host/home/singimhale/repos/ws2021_team_3_ads/TestApp/components/TestApp/src/TestApp.c:42: 2 - parking_spot: start: x: 96.392823
y: 8.218225 | end: x: 99.337284 | y: 8.250839 | length: 2.945159
INFO: /host/home/singimhale/repos/ws2021_team_3_ads/TestApp/components/TestApp/src/TestApp.c:42: 3 - parking_spot: start: x: 184.263688
y: 8.351658 | end: x: 112.613875 | y: 8.497448 | length: 8.358669
ERROR: /host/home/singimhale/repos/trentos/sdk/libs/os_filesystem/src/lib/SpiffsFile.c:61: Spiffs_open() failed with -10002
INFO: /host/home/singimhale/repos/ws2021_team_3_ads/TestApp/components/TestApp/src/TestApp.c:177: Demo completed successfully.

# Container ads-pythonclient-1 Created
Attaching to ads-carla-1, ads-pythonclient-1
ads-carla-1 | ALSA lib conf.c:767:(parse_card) cannot find card '0'
ads-carla-1 | ALSA lib conf.c:4528:(snd_config_evaluate) function snd_func_card_driver returned error: No such file or directory
ads-carla-1 | ALSA lib conf.c:392:(snd_func_concat) error evaluating strings
ads-carla-1 | ALSA lib conf.c:4528:(snd_config_evaluate) function snd_func_card_driver returned error: No such file or directory
ads-carla-1 | ALSA lib conf.c:1246:(snd_func_refer) error evaluating name
ads-carla-1 | ALSA lib conf.c:4528:(snd_config_evaluate) function snd_func_refer returned error: No such file or directory
ads-carla-1 | ALSA lib conf.c:3807:(snd_config_expand) Evaluate error: No such file or directory
ads-carla-1 | ALSA lib pcm.c:2495:(snd_pcm_open_noupdate) Unknown PCM default
ads-carla-1 | ALSA lib conf.c:767:(parse_card) cannot find card '0'
ads-carla-1 | ALSA lib conf.c:4528:(snd_config_evaluate) function snd_func_card_driver returned error: No such file or directory
ads-carla-1 | ALSA lib conf.c:392:(snd_func_concat) error evaluating strings
ads-carla-1 | ALSA lib conf.c:4528:(snd_config_evaluate) function snd_func_card_driver returned error: No such file or directory
ads-carla-1 | ALSA lib conf.c:1246:(snd_func_refer) error evaluating name
ads-carla-1 | ALSA lib conf.c:4528:(snd_config_evaluate) function snd_func_refer returned error: No such file or directory
ads-carla-1 | ALSA lib conf.c:3807:(snd_config_expand) Evaluate error: No such file or directory
ads-carla-1 | ALSA lib pcm.c:2495:(snd_pcm_open_noupdate) Unknown PCM default
ads-pythonclient-1 | /usr/lib/python3/dist-packages/pkg_resources/_init_.py:1235: UserWarning: (/tmp/egg-cache is writable by group/others
and vulnerable to attack when used with get_resource_file_name. Consider a more secure location (set with --set_extraction_path of the PYTHON
EGG_CACHE environment variable))
ads-pythonclient-1 | warnings.warn(msg, UserWarning)
ads-pythonclient-1 | Connecting to localhost:2800
ads-pythonclient-1 | Current world Town03
ads-pythonclient-1 | Created vehicle test1 cybertruck
ads-pythonclient-1 | Created sensor camera_rgb
ads-pythonclient-1 | parking position: [113.67434992,382812.8, 8.515972137451372]
ads-pythonclient-1 | Start parking...

```

# Practical Phase – Results: Robotic Simulator

The image shows a robotic simulator interface. On the left, a terminal window displays logs for a simulation. The logs indicate that a simulation operation is completed and the robot is waiting for joint angles to reach target values. It then proceeds to interact with a cube, receiving instructions from a pyServer to grab, drop, and turn. The logs are organized into sections for 'CUBE No. 4' and 'CUBE No. 5'. A large blue watermark 'speed 400%' is overlaid on the terminal output.

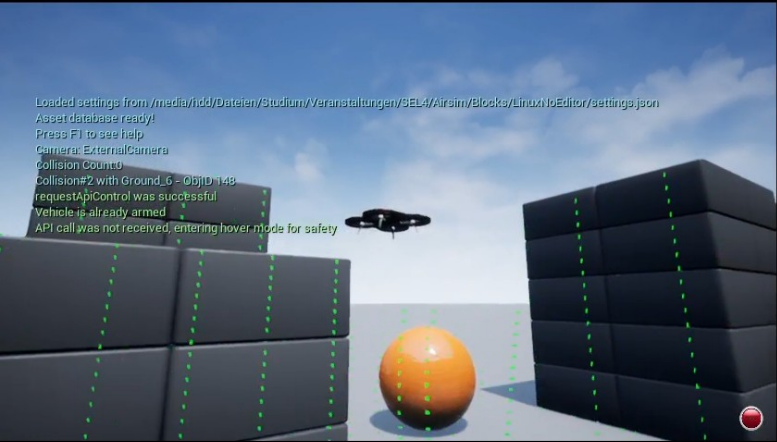
On the right, the 3D simulator view shows a robot with a gripper positioned over a red cube on a table. The robot is labeled 'cuboidRobot'. The interface includes a menu bar (File, Edit, Add, Simulation, Tools, Plugins, Add-ons, Scenes, Help) and a toolbar with various simulation controls.

At the bottom, a network traffic capture window is visible, showing a list of captured packets. The table below represents the data shown in this window:


No.	Time	Source	Destination	Protoc	Len	Info
700	259.433989256	10.0.0.11	10.0.0.10	TCP	71	51292 → 2021 [PSH, ACK] Seq=193 Ack=193 Win=...
701	259.434148263	10.0.0.10	10.0.0.11	TCP	67	2021 → 51292 [PSH, ACK] Seq=193 Ack=194 Win=...
702	259.437278537	10.0.0.11	10.0.0.10	TCP	70	51292 → 2021 [ACK] Seq=194 Ack=194 Win=16383...
703	260.441593361	10.0.0.11	10.0.0.10	TCP	71	51292 → 2021 [PSH, ACK] Seq=194 Ack=194 Win=...
704	260.441719516	10.0.0.10	10.0.0.11	TCP	67	2021 → 51292 [PSH, ACK] Seq=194 Ack=195 Win=...
705	260.443714199	10.0.0.11	10.0.0.10	TCP	71	[TCP Keep-Alive] 51292 → 2021 [PSH, ACK] Seq=...
706	260.443741325	10.0.0.10	10.0.0.11	TCP	78	[TCP Keep-Alive ACK] 2021 → 51292 [ACK] Seq=...
707	260.443756221	10.0.0.11	10.0.0.10	TCP	70	51292 → 2021 [ACK] Seq=195 Ack=195 Win=16383...
708	61.48341194	10.0.0.11	10.0.0.10	TCP	71	51292 → 2021 [PSH, ACK] Seq=195 Ack=195 Win=...
709	61.4836601	10.0.0.10	10.0.0.11	TCP	66	2021 → 51292 [ACK] Seq=195 Ack=196 Win=65280...
710	61.4843069	10.0.0.11	10.0.0.10	TCP	67	2021 → 51292 [PSH, ACK] Seq=195 Ack=196 Win=...
711	61.4847887	10.0.0.10	10.0.0.11	TCP	70	51292 → 2021 [ACK] Seq=196 Ack=196 Win=16383...
712	262.459185297	10.0.0.11	10.0.0.10	TCP	71	51292 → 2021 [PSH, ACK] Seq=196 Ack=196 Win=...
713	262.459234118	10.0.0.10	10.0.0.11	TCP	66	2021 → 51292 [ACK] Seq=196 Ack=197 Win=65280...
714	262.459389694	10.0.0.10	10.0.0.11	TCP	67	2021 → 51292 [PSH, ACK] Seq=196 Ack=197 Win=...
715	262.463637576	10.0.0.11	10.0.0.10	TCP	70	51292 → 2021 [ACK] Seq=197 Ack=197 Win=16383...
716	263.468192696	10.0.0.11	10.0.0.10	TCP	71	51292 → 2021 [PSH, ACK] Seq=197 Ack=197 Win=...
717	263.468487307	10.0.0.10	10.0.0.11	TCP	66	2021 → 51292 [ACK] Seq=197 Ack=198 Win=65280...
718	263.468931625	10.0.0.10	10.0.0.11	TCP	67	2021 → 51292 [PSH, ACK] Seq=197 Ack=198 Win=...
719	263.473736574	10.0.0.11	10.0.0.10	TCP	70	51292 → 2021 [ACK] Seq=198 Ack=198 Win=16383...

# Practical Phase – Results: Drone Simulator + SPI LED

## AirSim



## Graphical output



## TRENTOS log

```

INFO: /host/home/haspa/ss2022_team_1_ds/airsim_lidar_lcd/components/TestApp/src/TestApp.c:
409: Block #24: -39.59, 279.08, 0.87

INFO: /host/home/haspa/ss2022_team_1_ds/airsim_lidar_lcd/components/TestApp/src/TestApp.c:
409: Block #27: -94.32, 265.62, 0.87

INFO: /host/home/haspa/ss2022_team_1_ds/airsim_lidar_lcd/components/TestApp/src/TestApp.c:
416: Vector to Destination is (24.99, 50.44, -25.88).

INFO: /host/home/haspa/ss2022_team_1_ds/airsim_lidar_lcd/components/TestApp/src/TestApp.c:
476: Vector of Flightpath 1 is (2.08, 4.20, -4.31).

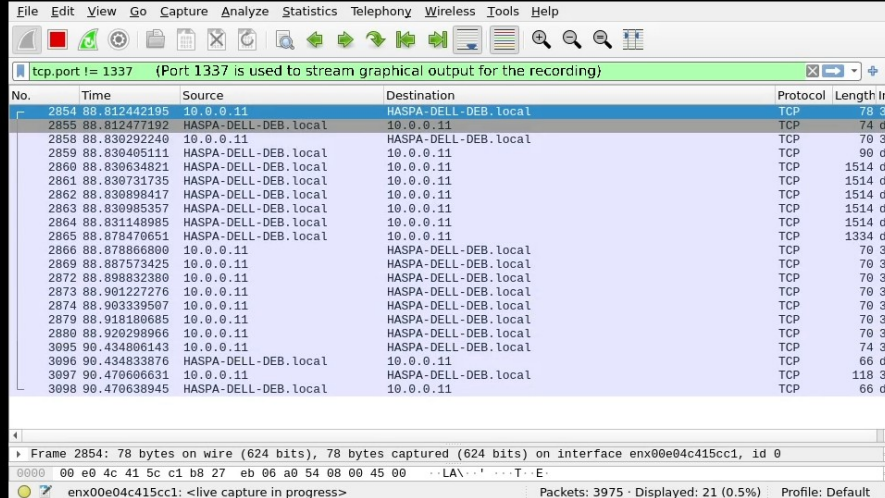
INFO: /host/home/haspa/ss2022_team_1_ds/airsim_lidar_lcd/components/TestApp/src/TestApp.c:
477: Vector of Flightpath 2 is (2.08, 4.20, -2.16).

INFO: /host/home/haspa/ss2022_team_1_ds/airsim_lidar_lcd/components/TestApp/src/TestApp.c:
478: Vector of Flightpath 3 is (2.08, 4.20, 0.00).

INFO: /host/home/haspa/ss2022_team_1_ds/airsim_lidar_lcd/components/TestApp/src/TestGraphi
cs.c:291: Drawing message "Flying"; it has extent (0, -6, 19, 1)

```

## Wireshark



No.	Time	Source	Destination	Protocol	Length	Info
2854	88.912442195	10.0.0.11	HASPA-DELL-DEB.local	TCP	78	33
2855	88.912477192	HASPA-DELL-DEB.local	10.0.0.11	TCP	74	d...
2858	88.830292240	10.0.0.11	HASPA-DELL-DEB.local	TCP	70	3...
2859	88.830405111	HASPA-DELL-DEB.local	10.0.0.11	TCP	90	d...
2860	88.830634821	HASPA-DELL-DEB.local	10.0.0.11	TCP	1514	d...
2861	88.830731735	HASPA-DELL-DEB.local	10.0.0.11	TCP	1514	d...
2862	88.830898417	HASPA-DELL-DEB.local	10.0.0.11	TCP	1514	d...
2863	88.830985357	HASPA-DELL-DEB.local	10.0.0.11	TCP	1514	d...
2864	88.831140905	HASPA-DELL-DEB.local	10.0.0.11	TCP	1514	d...
2865	88.87470651	HASPA-DELL-DEB.local	10.0.0.11	TCP	1334	d...
2866	88.878866800	10.0.0.11	HASPA-DELL-DEB.local	TCP	70	3...
2869	88.887573425	10.0.0.11	HASPA-DELL-DEB.local	TCP	70	3...
2872	88.898832380	10.0.0.11	HASPA-DELL-DEB.local	TCP	70	3...
2873	88.901227276	10.0.0.11	HASPA-DELL-DEB.local	TCP	70	3...
2874	88.903339507	10.0.0.11	HASPA-DELL-DEB.local	TCP	70	3...
2879	88.918180695	10.0.0.11	HASPA-DELL-DEB.local	TCP	70	3...
2880	88.920298966	10.0.0.11	HASPA-DELL-DEB.local	TCP	70	3...
3095	90.434806143	10.0.0.11	HASPA-DELL-DEB.local	TCP	74	3...
3096	90.434833876	HASPA-DELL-DEB.local	10.0.0.11	TCP	66	d...
3097	90.470606631	10.0.0.11	HASPA-DELL-DEB.local	TCP	118	3...
3098	90.470638945	HASPA-DELL-DEB.local	10.0.0.11	TCP	66	d...

# Future Work

- Application of further simulators
- Extension to cryptographic use cases
  - via TRENTO Crypt API
  - via dedicated hardware components
- Application of RISC-V as underlying hardware platform (e.g. via QEMU)
- Utilization of seL4 virtualization facilities from within TRENTO, running a Linux VM and native TRENTO components side-a-side

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