VILLASframework

A framework for
Virtually Interconnected Laboratories for LArge systems Simulation/emulation

Institute for Automation of Complex Power Systems (ACS)
RWTH Aachen University
Germany

Prof. Antonello Monti, Ph. D.

ACS | Automation of Complex Power Systems

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VILLAS
Framework for virtual integration of laboratories for co-simulation

- **VILLAS**framework - Virtually Interconnected Laboratories for LArge systems Simulation/emulation
  - a flexible integration of the resources available at each laboratory
  - a flexible utilization of an infrastructure as a whole

- VILLASframework aims at providing a specific set of interfaces and services
  - hard and soft real-time interfaces
    - integration of geographically dispersed hardware and software assets for joint operation in a single experiment
  - high-level interfaces such as a user interface, an interface for data logging
    - interactions with an experiment and post-processing of results for further analyses
  - high-level services, such as Simulation as a Service, Data as a Service
    - flexible access for third parties to leverage utilization of the infrastructure

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# VILLASframework
High-level architecture overview

- **General design objectives**

  - A holistic framework with modular and generic architecture

  - Portability of interfaces among laboratories for integration of different local assets
    (digital real-time simulators, measurement devices, estimation and control algorithms)

  - Plug-and-play framework for geographically distributed test beds and co-simulation

- **The main pillars of VILLASframework**

  - **VILLASnode**   Gateway for connecting simulation equipement

  - **VILLASfpga**   Extendended hard-realtime capabilties and FPGA-based models

  - **VILLASweb**   Planning, Execution and Analysis of complex simulation scenarios

  - **VILLAScontroller** Unified API for controlling DRTS (OPAL, RTDS, Simulink)
    (planned)

VILLASnode
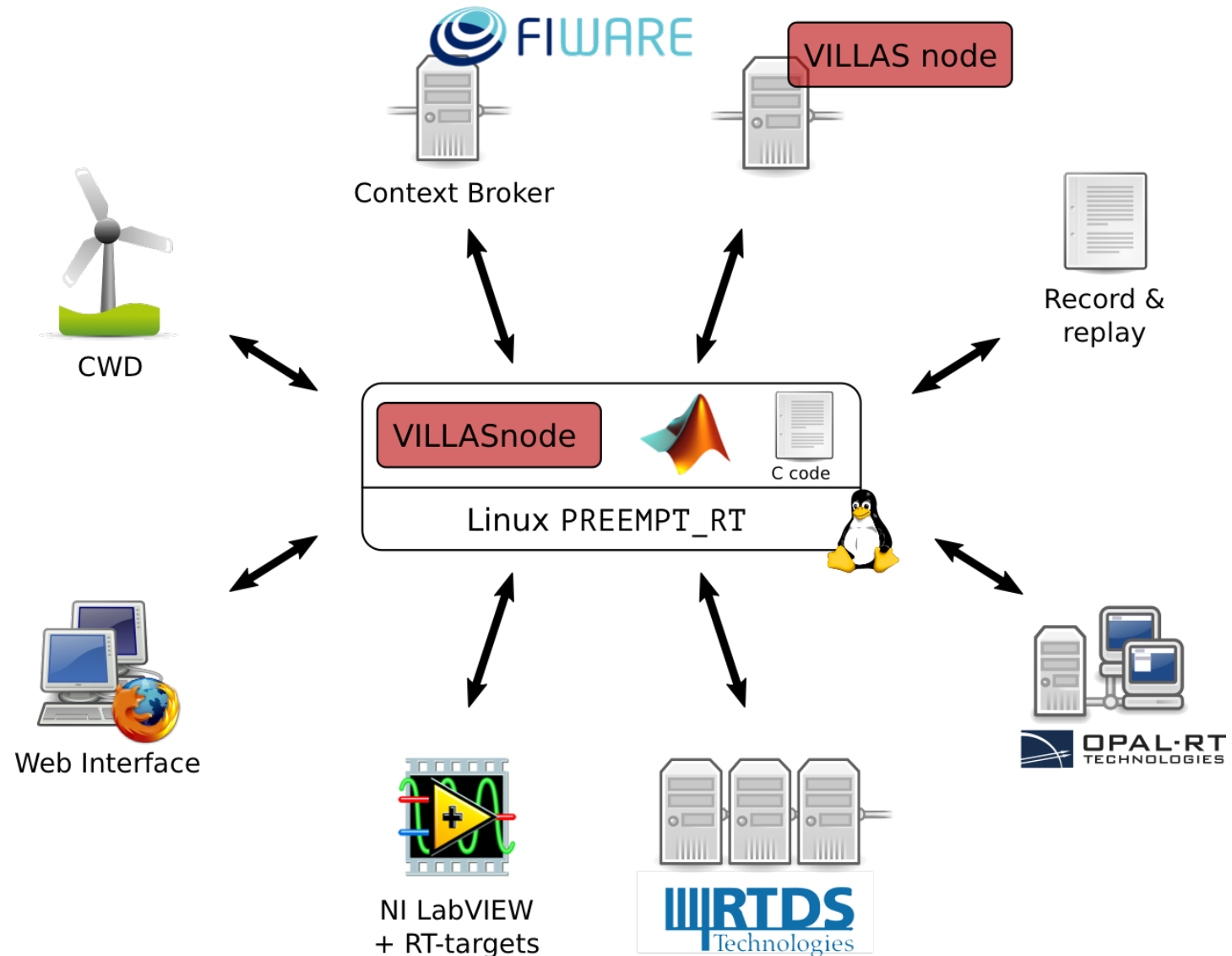# Design decisions
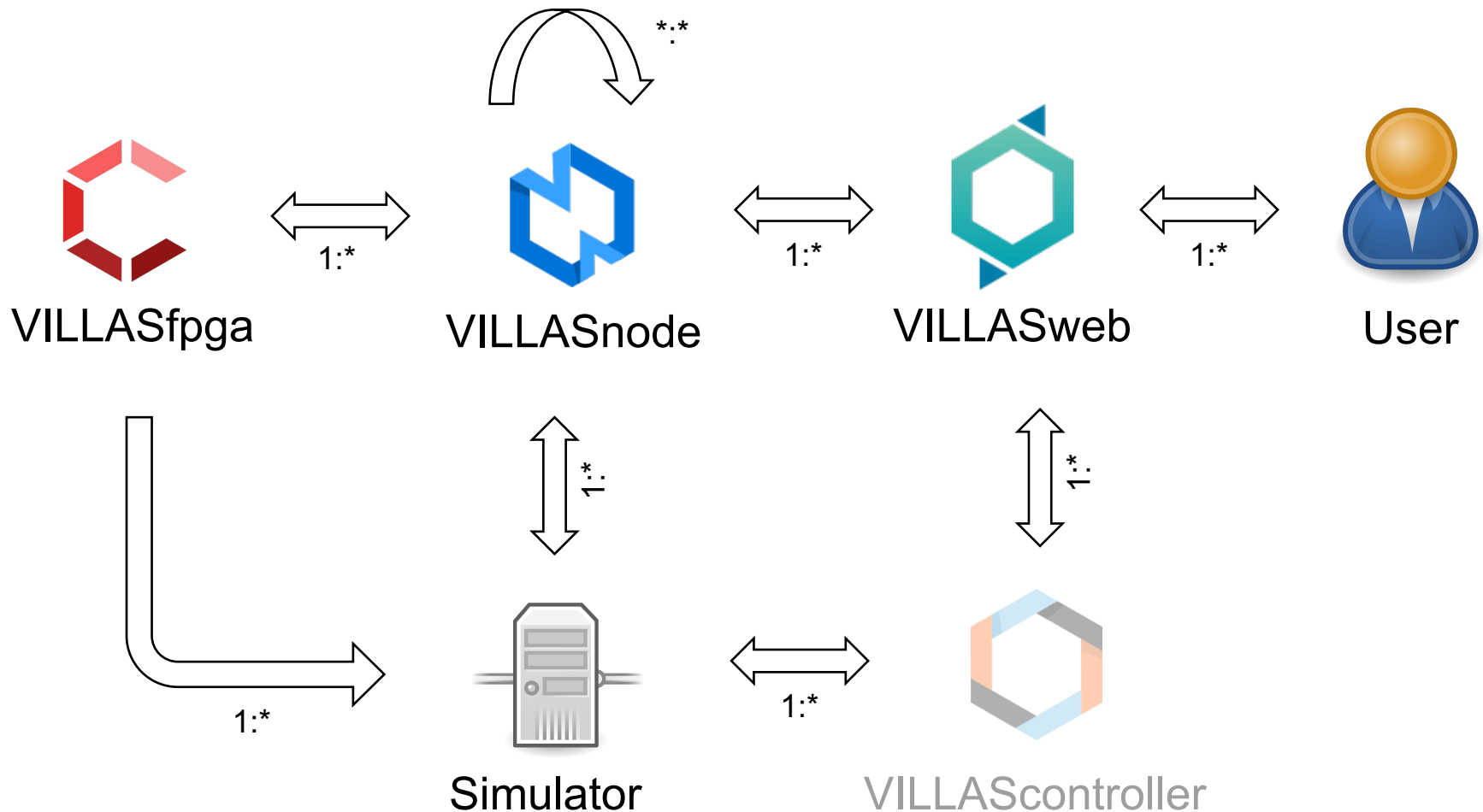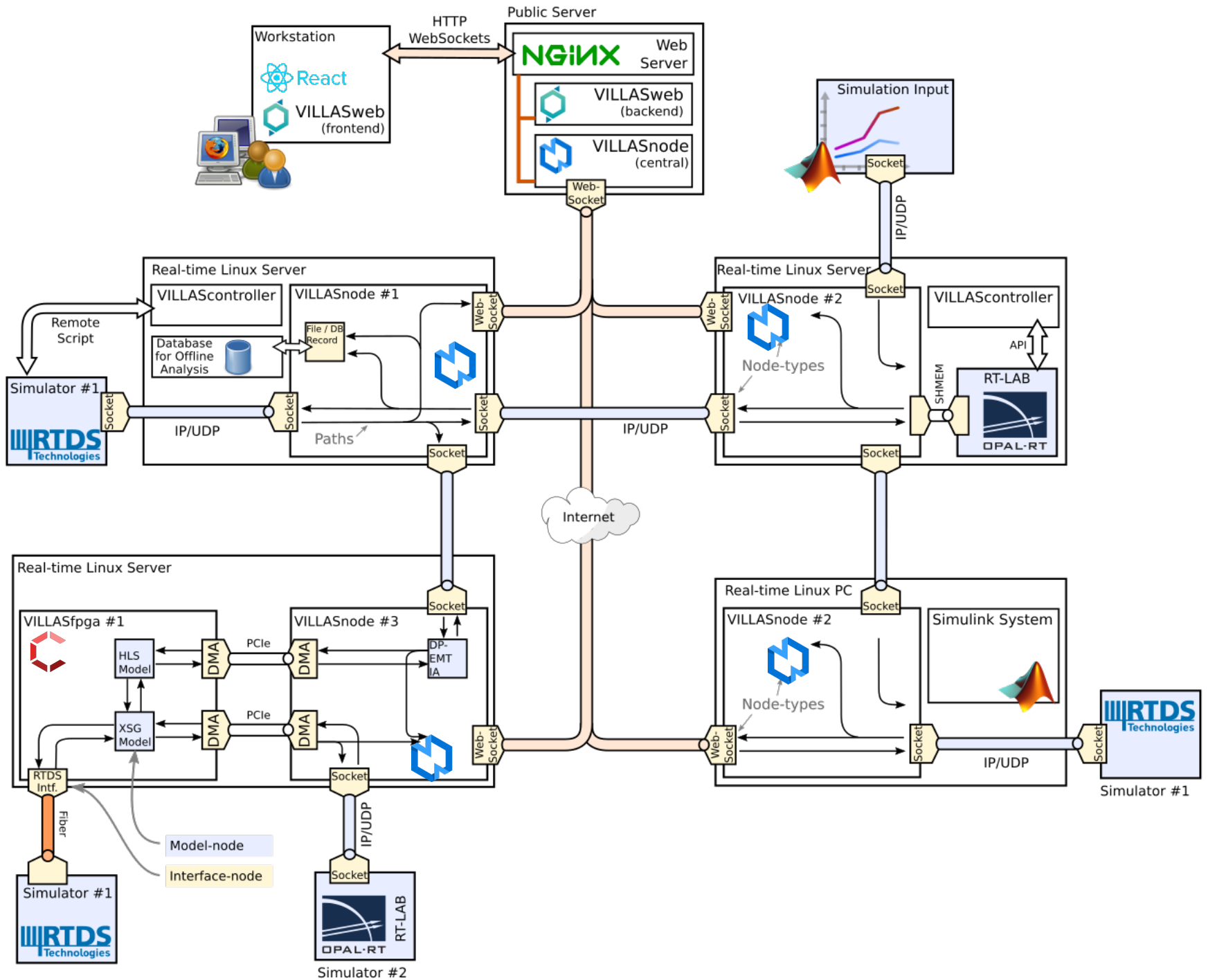
■ Make an interface as transparent to the simulator/hardware as possible

**Goals** ➜ Low & deterministic latency

■ Object oriented **low-level C** for best performance

■ Make use of **Linux real-time** features (`PREEMPT_RT` patchset)

■ Multi-threaded, non-blocking design

■ Reserved CPU cores for execution

■ Only depends on **open source** tools & libraries

VILLASnode
Overview

- Router for sample / value based simulation data
  - ≡ **1-to-n** forwarding of sample values
  - ≡ MUX and DEMUX supported
  - ≡ Concept of <u>unidirectional</u> **paths**, **nodes** & **hooks**

VILLASnode
Concept
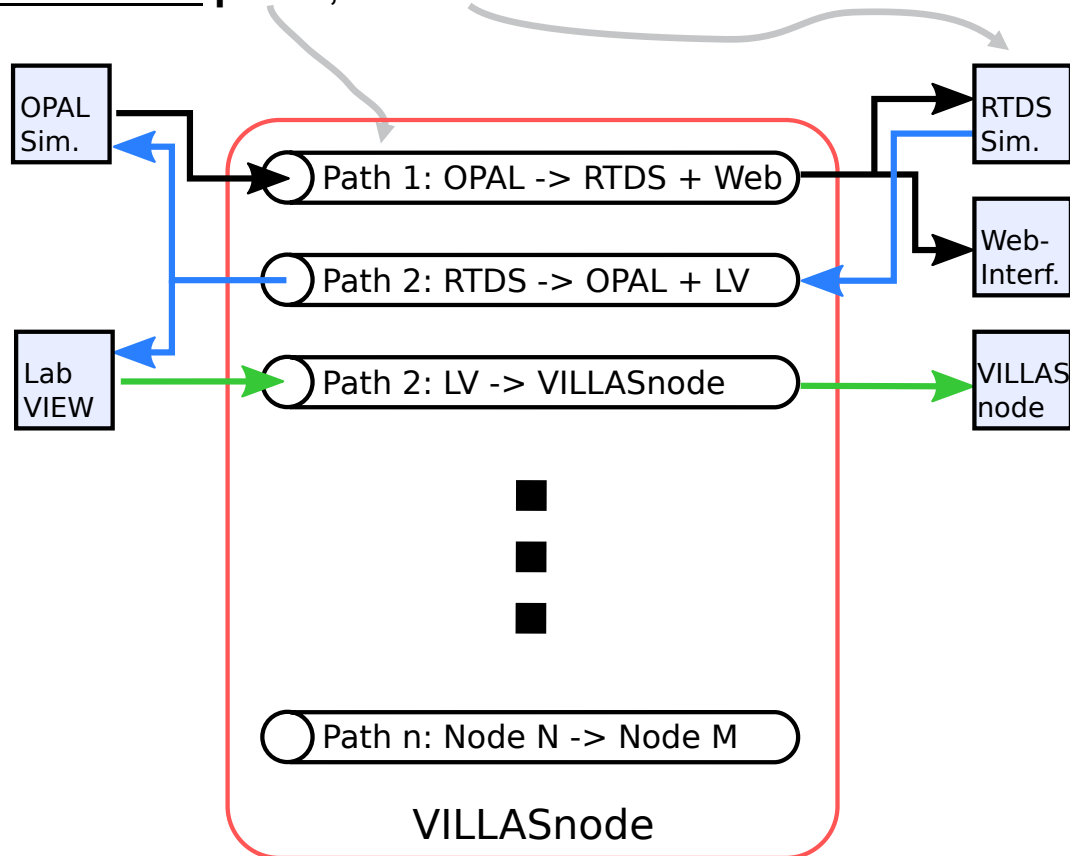
- **Nodes**
  - Representation of a Simulator / Model
  - Two types:
    - Model: runs on same machine
    - Interface: connect an external simulator
  - Acts as a source or sink of samples

- **Paths**
  - Unidirectional connection between nodes: 1-to-N (1 source, N sinks)
  - Hook functions
    - Interface algorithms
    - Dynamic phasor conversion (DFT)
    - Down-sampling
    - Timestamping
    - Collect statistics

- **Hooks**
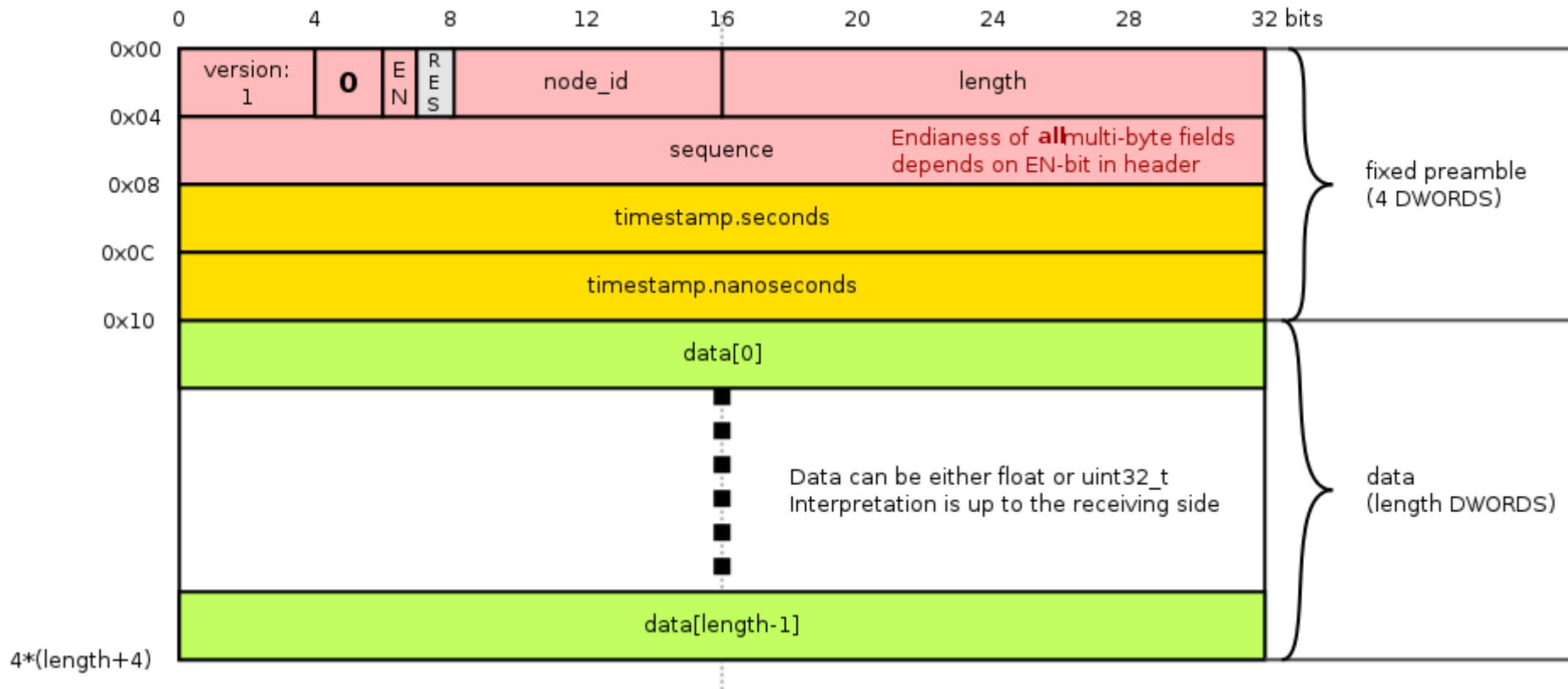 - Process / Filter the forwarded data with user-defined functions

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VILLASnode
Node-types

Node-type	Description	Note
socket	Standard BSD Sockets	UDP, IP, IEEE802.3 Support for RTDS' GTNETv2-SKT
websocket	Connection-oriented interface for webbrowsers	• Firefox Browser • VILLASweb
ngsi	Next Genereration Services Interface	FIWARE Orion Context Broker
file	Reading and logging from files on harddisk	• Static load profile • Replay
opal	OPAL-RT Shared Memory	Not synchronized (libOpalAsyncApi)
fpga	VILLASfpga	PCIe Interface + DMA to RTDS (GTFPGA)

VILLASnode
Node-types (cont'd)

Node-type	Description	Note
cbuilder	Run RTDS Cbuilder components	(depracted)
shmem	Shared memory to processes running on the same machine	(ongoing)
register	(De-) Multiplex to / from multiple nodes	(ongoing)

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VILLASnode
Network Packet Format for socket and websocket node-types

This protocol is only used by socket and websocket node-types!
Each node-type can define it's own protocol (e.g. NGSI uses HTTP REST + JSON)

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VILLASnode
Tools / Applications

- **Main server:**   `villas node`
  - ≡ Runs one or more paths
  - ≡ Multi-threaded
  - ≡ Collects statistics
  - ≡ Filter / Process data with hook functions
- **Signal generator:**   `villas signal`
  - ≡ Generate square, sine, ramp, triangle and random signals
  - ≡ Adjustable timestep, amplitude & frequency
- **Read / write from / to stdin / stdout:**   `villas pipe`
  - ≡ Pipe to / from files
  - ≡ User input
  - ≡ Debugging
- **Run hooks with stdin / stdout data**   `villas hook`

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VILLASnode
Features Overview

- Supports heterogenous environments
  - OPAL-RT
  - RTDS
  - LabVIEW
  - Custom Ethernet / IP / TCP & UDP Transports
- Synchronization
  - Timestamping
  - NTP / PTP
  - Fixed Rate Sending
- QoS Monitoring
- Network Emulation
- Flexible Hook Functions
  - Dropping of re-ordered UDP packets
  - FIR Filtering
  - Logging
  - Much more...

- Tools
  - Generate random data
  - Manual send / receive
  - Replay
- Very low-latency forwarding
  - Thread / IRQ Pinning
  - CPU isolation
  - Zero-copy
  - Multithreaded

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VILLASnode
Deployment

- ACS provides support for deploying VILLASnode instances

- Distribution
  - Docker images for non real-time crititcal applications / development / testing
  - Ready-to-go USB live image or installer based on Fedora Linux
  - RPM Software packages for CentOS / Fedora / Redhat

- Development
  - Collaboration & patches are welcome
  - We use GitLab for project management
  - VILLASnode software is distributed under LGPLv2 license

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VILLASnode Requirements

- Network
  - Direct GigEthernet connection to OPAL-RT/RTDS
  - Separate Ethernet connection to the Internet
- Commodity PC / Server
  - Intel **x86-64** architecture
  - Bare metal Linux-based operating system
    - No background processes & GUI
  - `RT_PREEMPT` Kernel Patch set
  - Nice to have:
    - Dual port Network Interface Card (NIC)
    - Support for IEEE-1588: Precision-Time-Protocol (PTP)
    - Recent Multicore CPU (for best determinism)
- Linux knowledge

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VILLASweb
Overview

■ Web interface for planning, controlling & analysing the distributed simulation

■ Work-in-Progress

■ The stages

1. Planning of simulation
   = Upload models
   = Upload input data
   = Map models onto simulators
2. Running simuation
   = Live-stream of selected Voltages / Currents / etc.
   = User interaction with button / sliders
3. Analysis / Collection of results
   = Download results to workstation

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VILLASweb

- Consolidated monitoring of the co-simulation with measurements from all subsystems
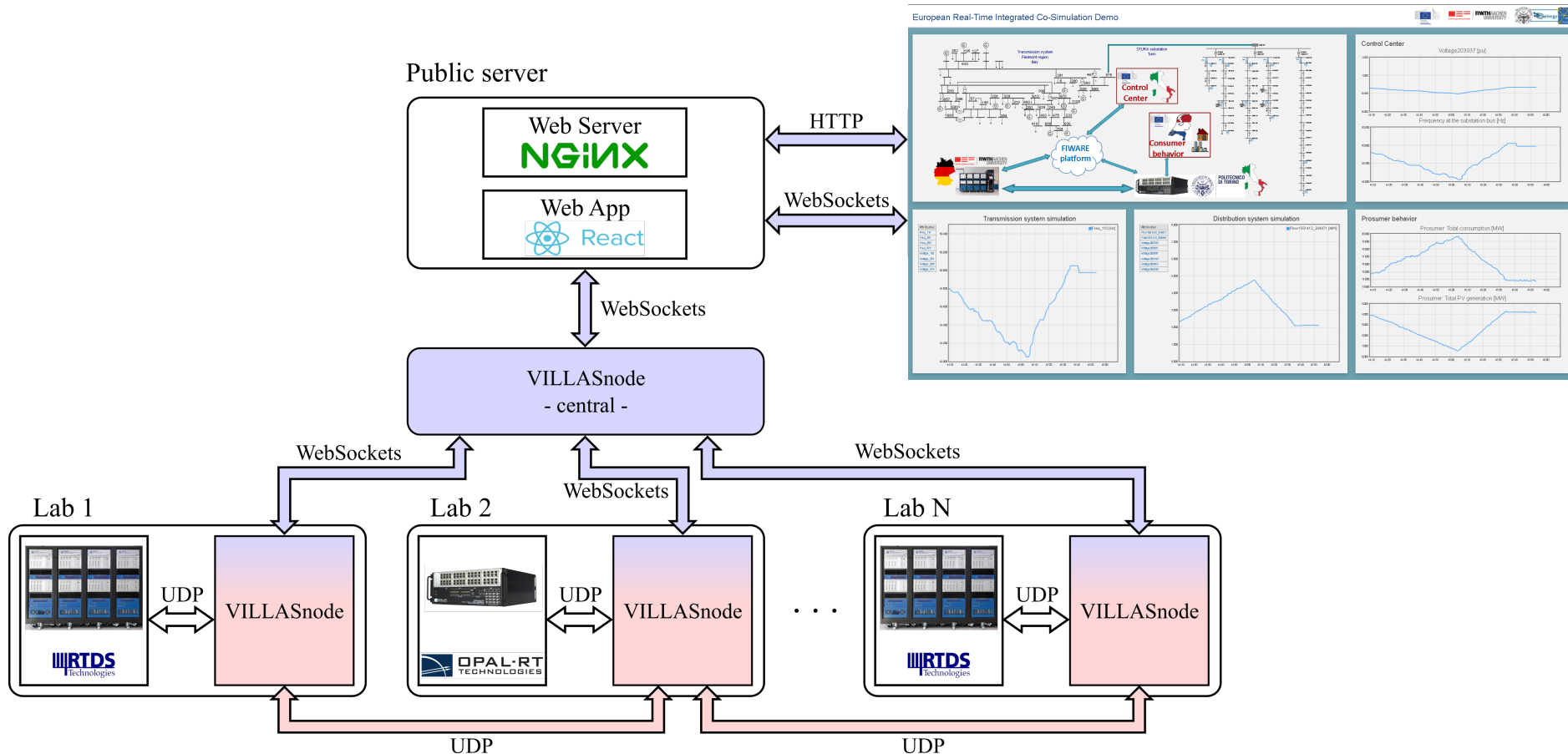
RT-Super Lab | Prof. Antonello Monti, Ph. D. | March 2017

VILLASweb Overview

- Identity Management

- Menu overview – Simulators
  - Status and configuration of simulators

VILLASweb
Overview (cont'd)

- Menu overview – *Simulations*
  - Multiple *Simulations* can be created and configured for available simulators
  - A *Simulation* refers to a setup of a co-simulation experiment with defined subsystem models
    - For instance, we can create multiple *Simulations* for RT-Super Lab Demo that refer to different stages of demo development

- ## Menu overview – *Simulation Models*
  - ≡ *Simulation* configuration requires configuration of *Simulation Models* for simulators that are included in the co-simulation experiment

Configure new Simulation Model

■ Menu overview – *Projects*

≡ Multiple *Projects* can be created and configured for a *Simulation*

= A *Project* can refer to a specific case study of a co-simulation experiment

■ Menu overview – *Visualizations*

≡ Multiple *Visualizations* can be created and configured for a *Project*

= A user can create different layouts (e.g. Summary or Detailed) for monitoring of simulation results

VILLASweb
Overview (cont'd)

■ A user can create a customized visualization of the co-simulation experiment

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VILLASfpga
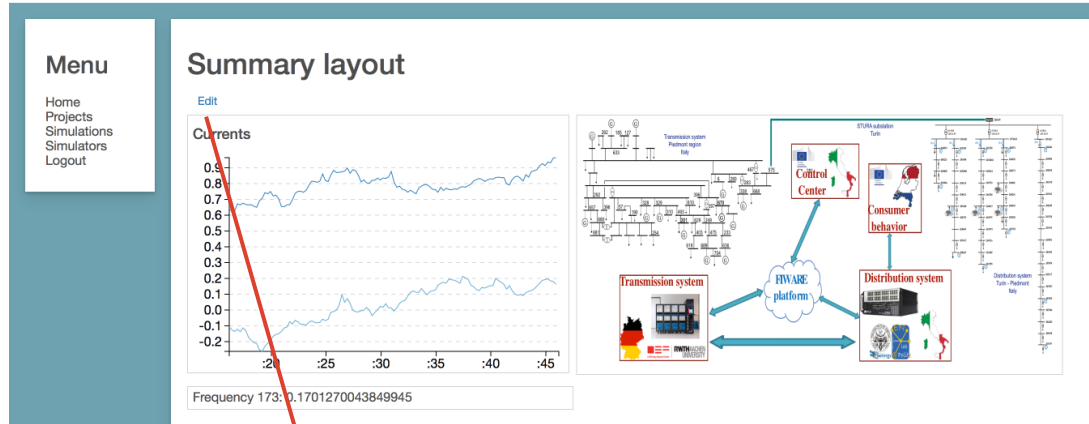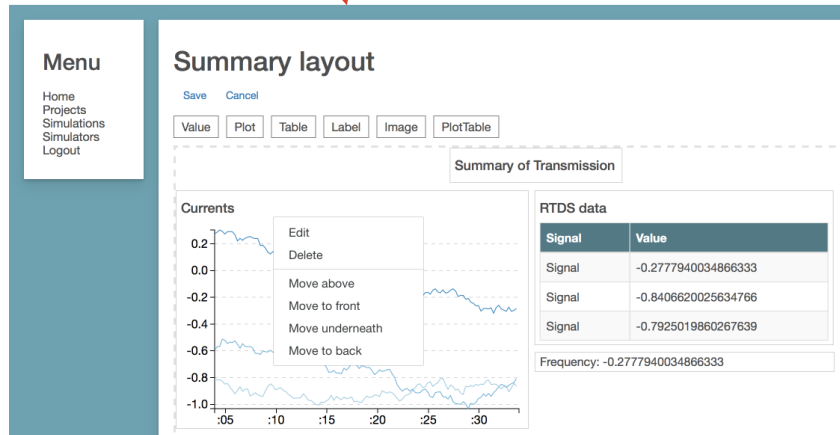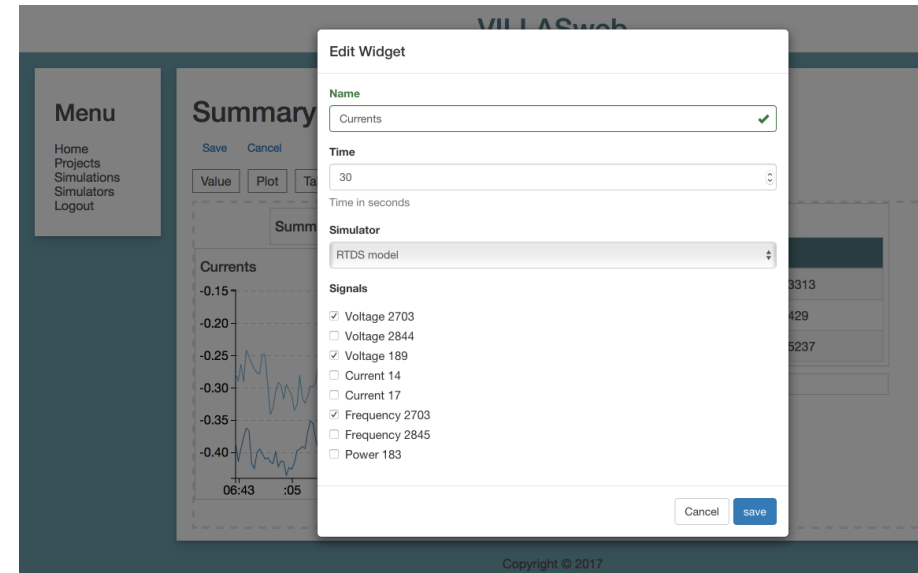
- Extend VILLASnode instances with FPGA ressources
  - Interface DRTS
    - RTDS via GTFPGA netlist
    - Typhoon, OPAL-RT via Aurora protocol

  - Run models / interface-algorithms
    - Simulink / Xilinx System Generator models
    - C++ code using High Level Synthesis

VILLAScontroller

- Provide a unified API for controlling a heterogenous environment of simulators
  - Load Model
  - Set Parameters
  - Start / Stop Simulation
  - Retrieve status of simulator

- Used by VILLASweb

- Planned for Q3/Q4 2017
  - Implemented in NodeJS

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Contact

E.ON Energy Research Center
Mathieustraße 10
52074 Aachen
Germany

Prof. Antonello Monti, Ph. D.
T +49 241 80 49703
F +49 241 80 49709
amonti@eonerc.rwth-aachen.de
http://www.eonerc.rwth-aachen.de

External Interconnections

Sintef, Norway

Joint Research Center, EU

Uni. South Carolina, US

Politecnico di Torino, Italy

ACS Real Time Lab

5 MW PGS Test Bench

1 MW On-Shore Wind Turbine Test Bench

4 MW On-Shore Wind Turbine Test Bench

Example of virtual integration over Wide Area Network
ERIC Lab demonstration

TRANSMISSION SYSTEM 380 – 220 kV
PIEDMONT REGION - ITALY

Aachen (Germany)

Transmission System Simulation

Turin (Italy)

Distribution System Simulation

Ispra (Italy)

Supervisor

DISTRIBUTION SYSTEM 22 KV –
A PORTION OF TURIN CITY - ITALY

Petten (Netherland)

Consumer Behavior Model

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VILLAS
Framework for virtual integration of laboratories for co-simulation

- Design objectives for a framework for virtual integration of laboratories
  - a flexible integration of the resources available at each laboratory
  - a flexible utilization of an infrastructure as a whole

- **VILLAS** framework - Virtually Interconnected Laboratories for LArge systems Simulation/emulation
  - ACS provides support setting up of VILLASnode at each laboratory involved in RT-Super Lab demo

Web-client for monitoring of the co-simulation with consolidated measurements from all subsystems

VILLASweb

VILLASnode

A single node for interfaces to
- OPAL-RT
- RTDS
- Websockets
- Orion Context Broker (FIWARE)
- Simulation data recording to a file

Note: distributed under LGPLv2 license

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