An Open-Source Framework for Developing Heterogeneous Distributed Enclave Applications

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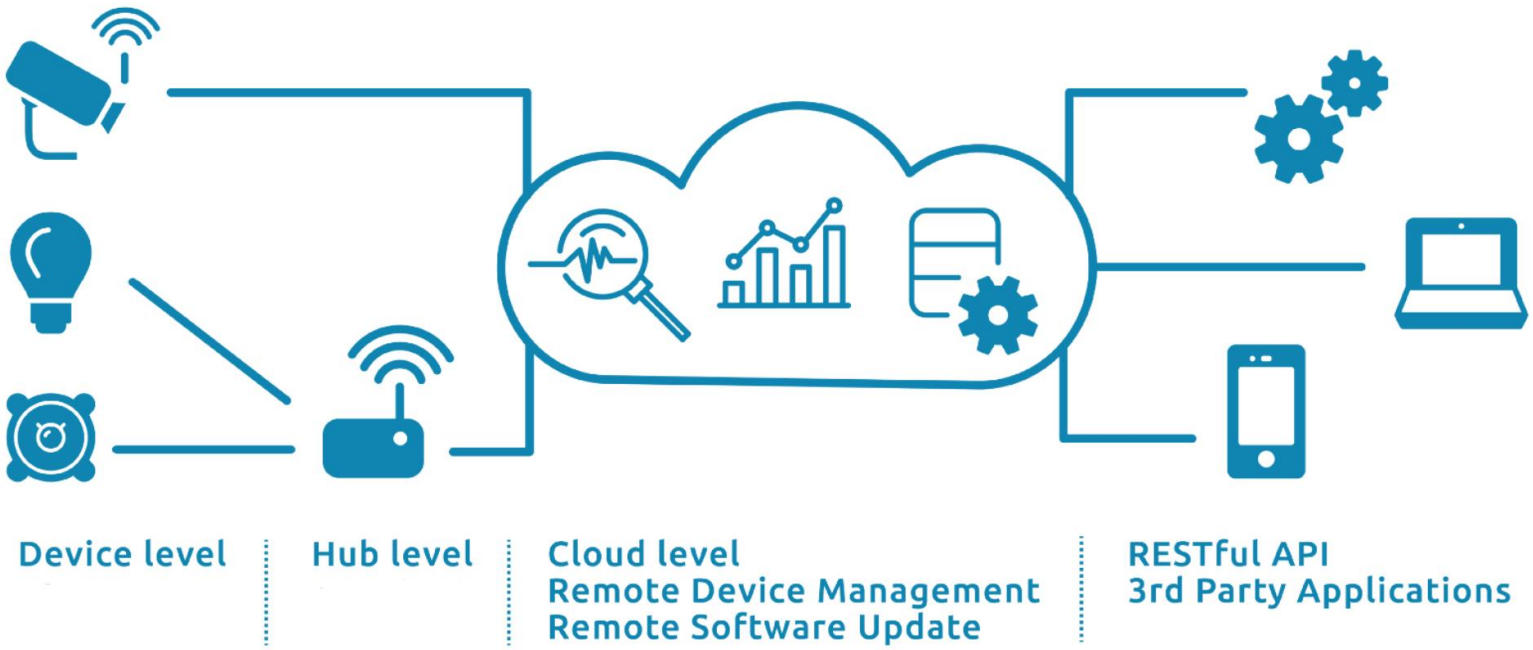
FOSDEM- Feb 2021

KU LEUVEN DistriNet

Security in Smart Environments



- ✓ The distributed applications runs on huge software and hardware stacks with multiple heterogeneous vendors everywhere. Which parts are trusted?
- ✓ Sensors come from heterogeneous vendors. Why would you trust them?
- ✓ The cloud is "other people's computers". Why trust them?
- ✓ Terminals may be used and managed by health care professionals. How to ensure the authenticity of data?

TEEs: Trusted Execution Environments

- ✓ **Isolation** of sensitive code and data
- ✓ **Authentication** of the running software (Remote Attestation)
- ✓ **Minimise Trusted Computing Base (TCB):**
  - ✓ Remove hypervisors, OSs, libraries from TCB
- ✓ **Reduction** of the attack surface
  - ✓ Only trust hardware and your own code

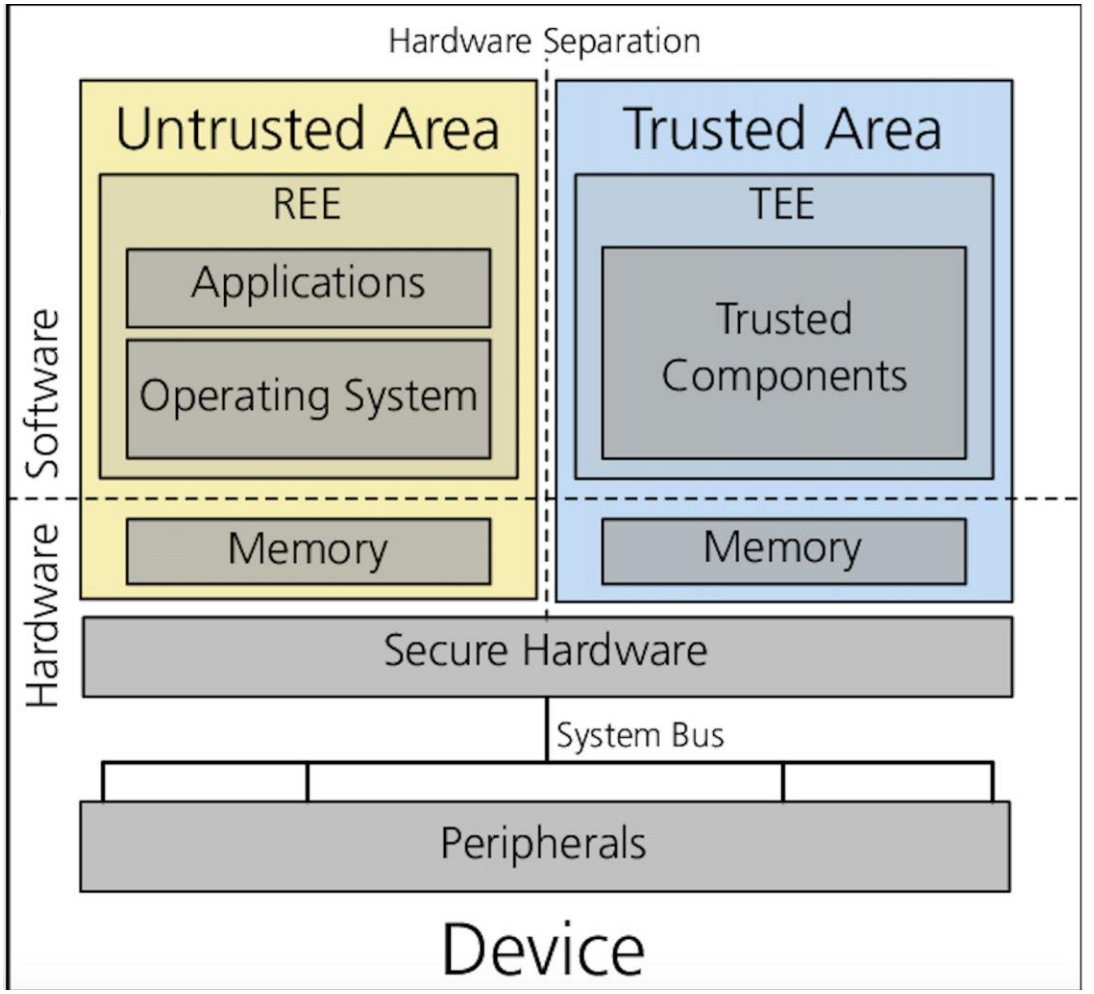
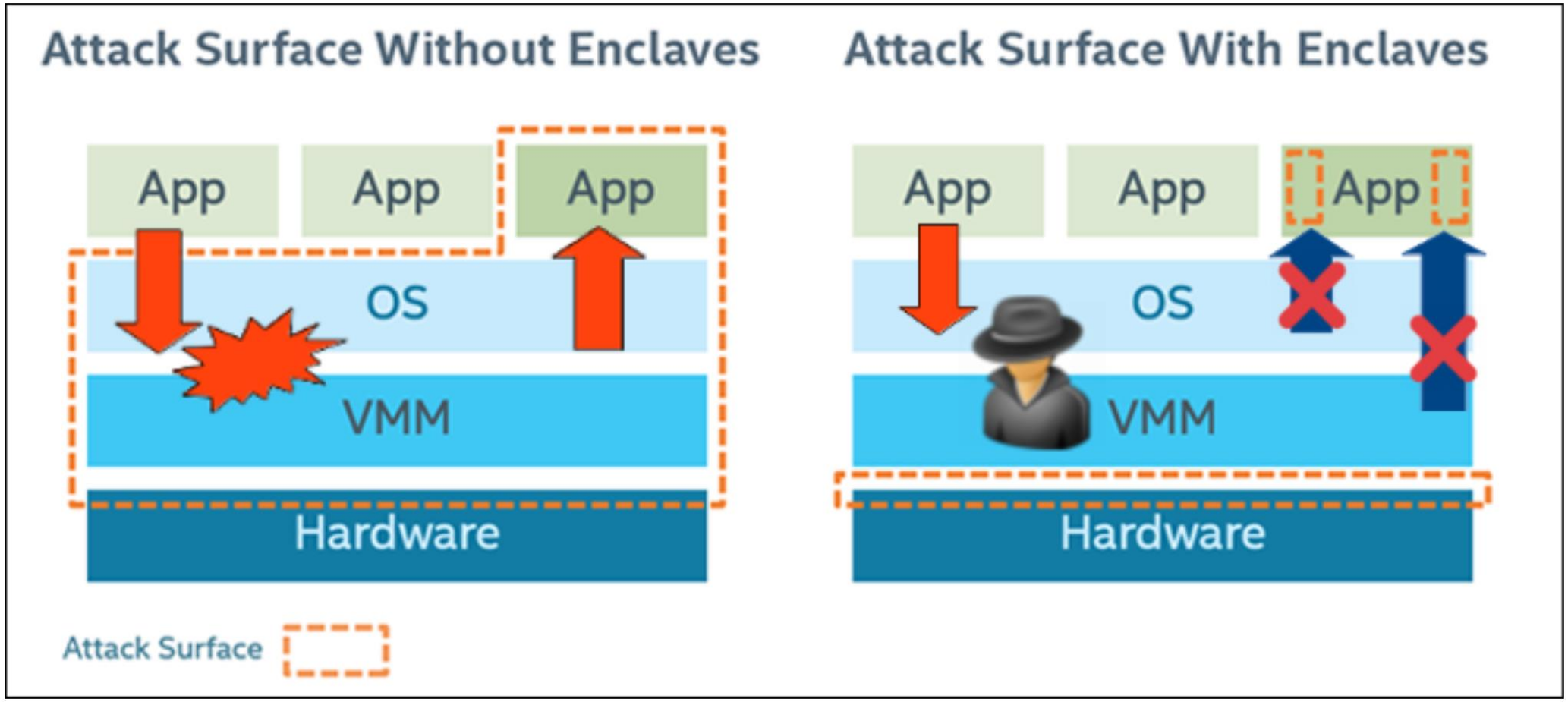


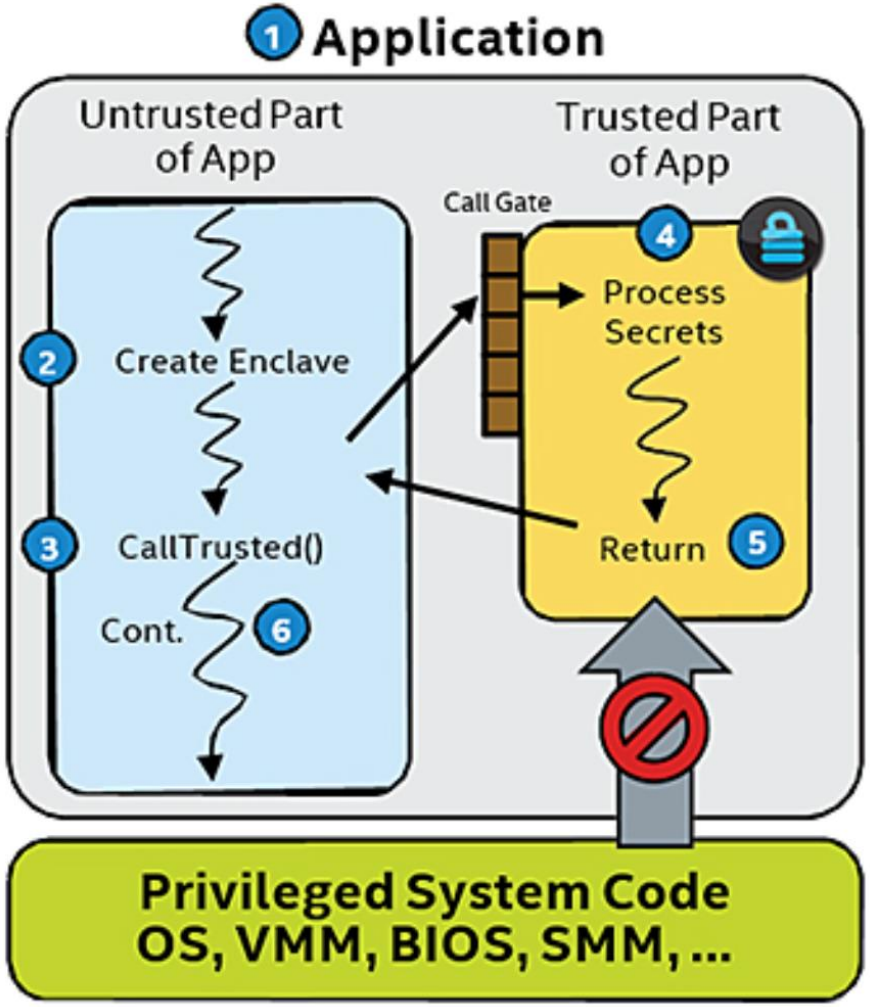
Fig. 1: An Overview of TEE Building Blocks

TEEs: Trusted Execution Environments



https://software.intel.com/content/www/us/en/develop/articles/intel-software-guard-extensions-tutorial-part-1-foundation.html

Intel SGX Helicopter View



https://software.intel.com/en- us/sgx/details

- ✓ Protected enclave in application's **virtual address space**
- ✓ Enclave can be entered through restrictive **call gate** only
- ✓ Provides **attestation** interface and **Data Sealing**
- ✓ **Memory encryption** defends against untrusted system software and cold boot attacks

ARM TrustZone®

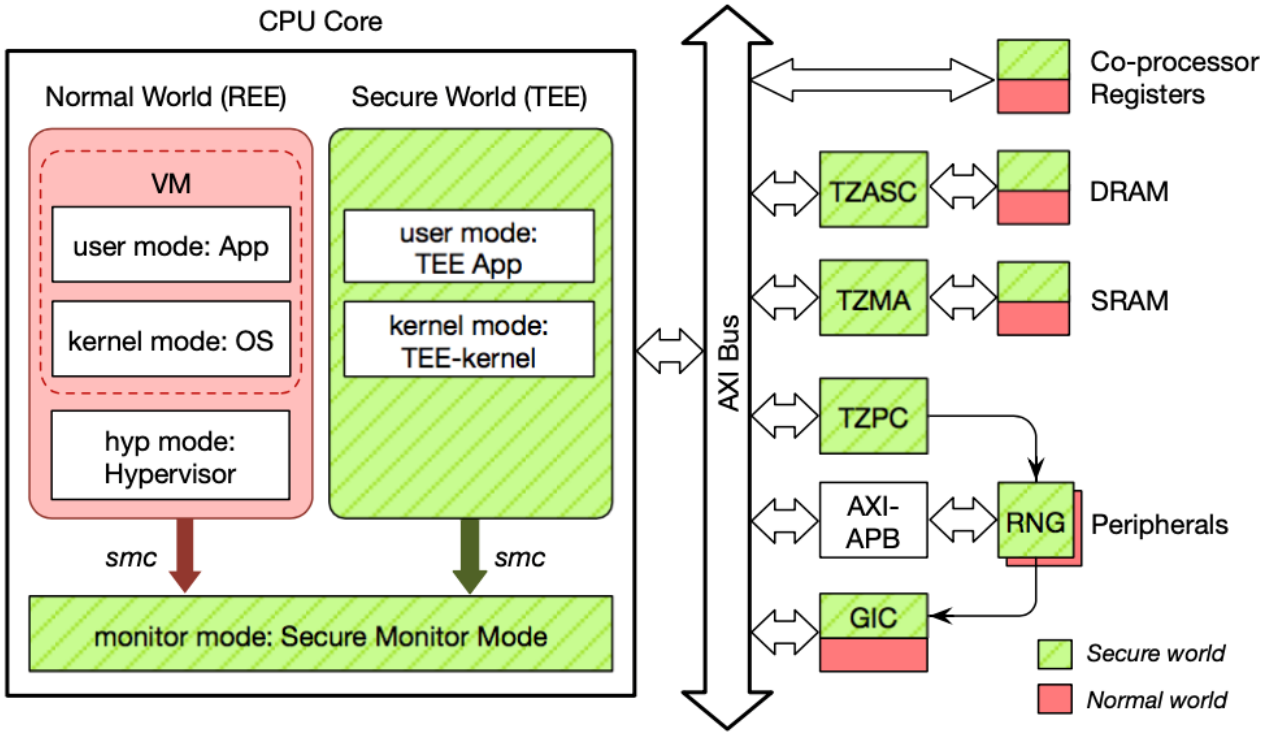
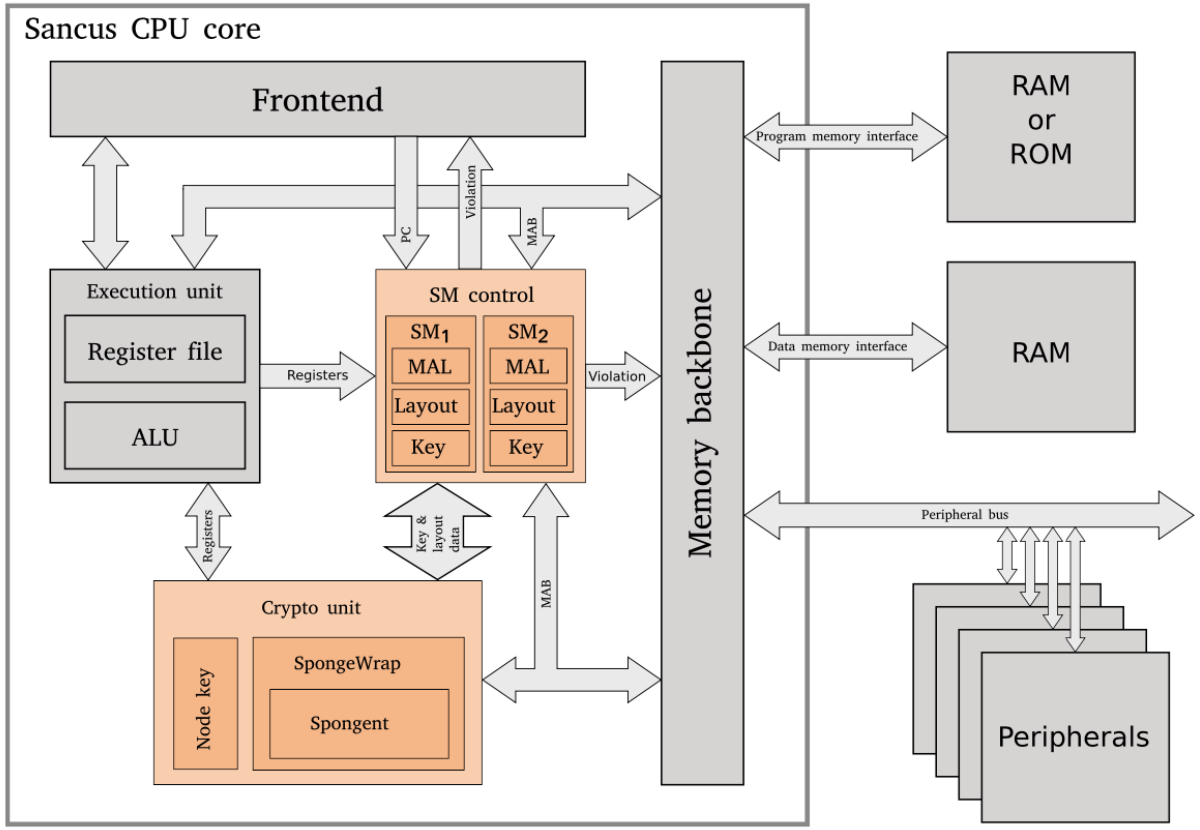


Fig. 2: High-level architecture of ARM TrustZone

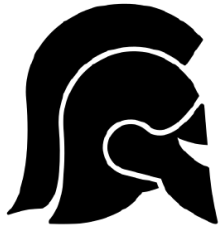
- ✓ Separating the CPU into the ***Normal World*** and the ***Secure World***
- ✓ Switching between two worlds through **Monitor Mode**
- ✓ **Memory and Peripheral Partitioning** into Secure/Non-secure regions
- ✓ Provides **Secure Boot**

Sancus: Strong and Light-Weight Embedded Security

- ✓ **Extends openMSP430 with strong security primitives**
  - ✓ Software Component Isolation
  - ✓ Cryptography & Attestation
  - ✓ Secure I/O through isolation of MMIO ranges
- ✓ **Cryptographic key hierarchy for software attestation**
- ✓ Isolated components are typically very small (< 1kLOC)



- ✓ Sancus is Open Source: https://distrinet.cs.kuleuven.be/software/sancus/



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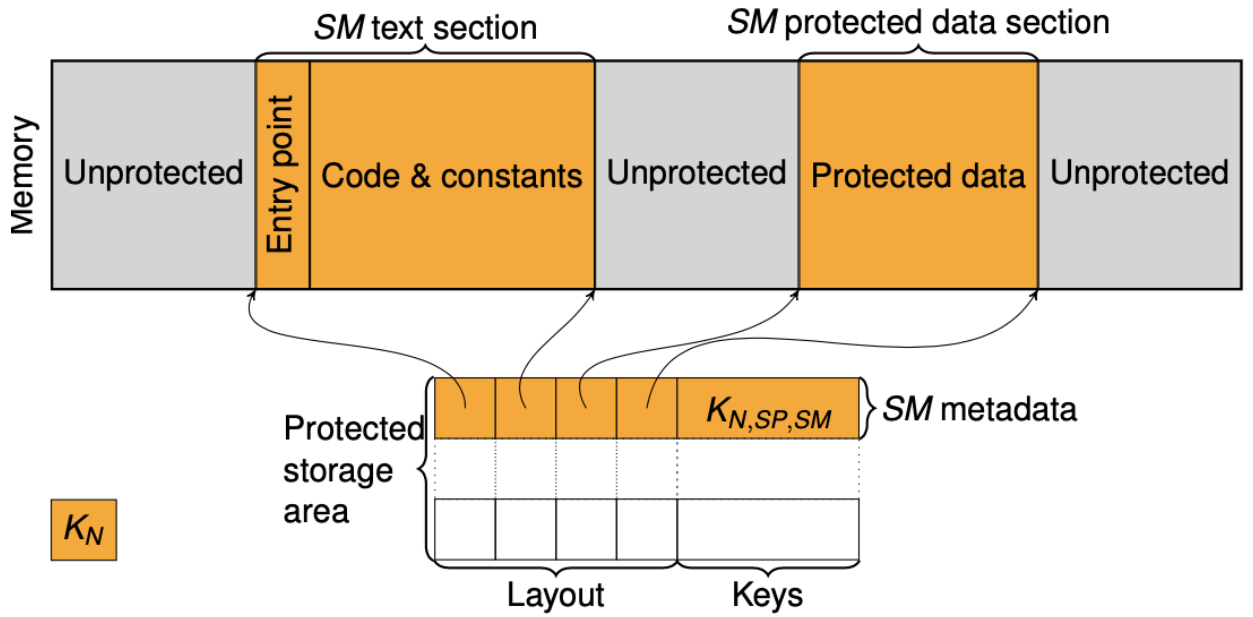
N = Node; *SP* = Software Provider / Deployer *SM* = protected Software Module



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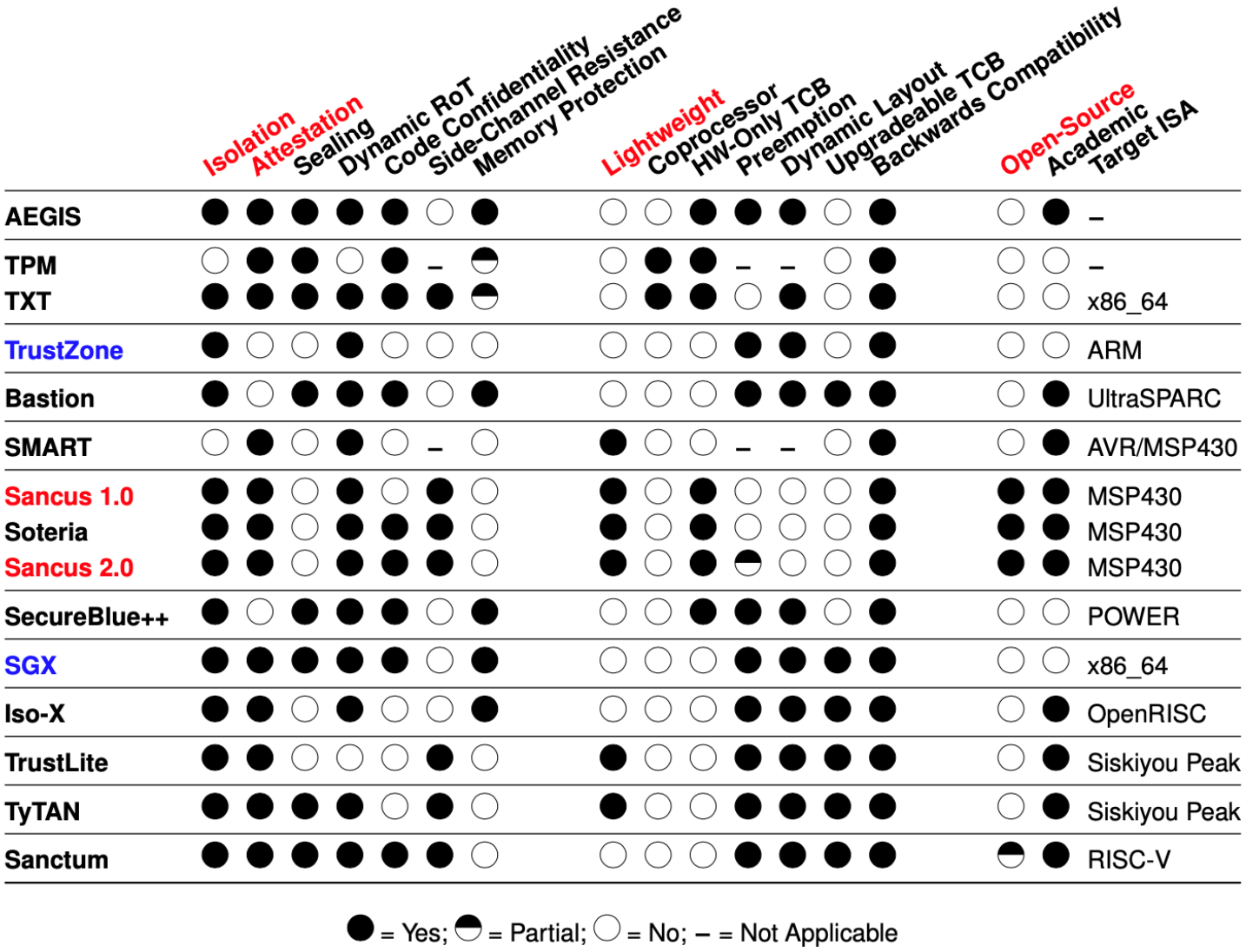
Comparing Hardware-Based Trusted Computing Architectures



Adapted from "Hardware-Based Trusted Computing Architectures for Isolation and Attestation", Maene et al., IEEE Transactions on Computers, 2017. [MGdC+ 17]

Authentic Execution

- ✓ Adapted from "Authentic Execution of Distributed Event-Driven Applications with a Small TCB", Noorman et al., [STM 2017]:

> *"if the application produces a physical output event (e.g., turns on an LED), then there must have happened a sequence of physical input events such that that sequence, when processed by the application (as specified in the high-level source code), produces that output event."*

- ✓ **Goal**: strong assurance of the secure execution of distributed event-driven applications on shared infrastructures with small TCB
- ✓ Its principles can be applied to any TEE -> **Heterogeneity**!

Our Framework Features

- ✓ For event-driven, distributed applications
- ✓ Supported **heterogeneous** TEEs:
  - ✓ SGX with Fortanix EDP
  - ✓ Open-Source Sancus
  - ✓ TrustZone with OP-TEE
- ✓ High Level of **Abstraction** over:
  - ✓ Platform-specific TEE layer
  - ✓ Secure communication API between modules
- ✓ Automatic deployment and Remote Attestation

A simple and secure distributed application using Sancus and SGX

FOSDEM 21

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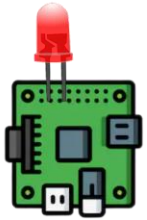
whoami

Gianluca Scopelliti

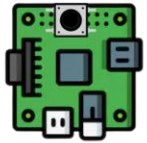
PhD student, ESR1 of the 5GhOSTS project promoted by KU Leuven and Ericsson

- *“Integrity assurance for multi-component services in 5G networks”*

Setup



node_sancus1



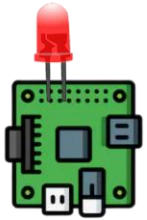
node_sancus2

node_sgx

deployer

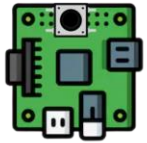
user

Setup



node_sancus1

Button: input of the system



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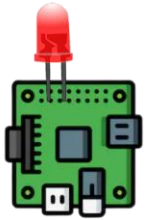
Setup

LED: toggled at every button press (ON/OFF)



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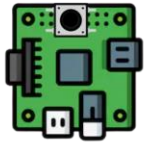

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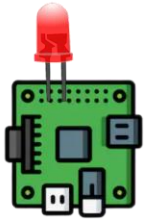

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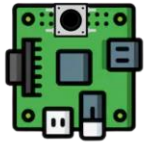


node_sancus2

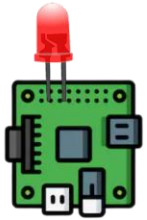
Store # of button presses, interface for deployer and external users

node_sgx

deployer

user

Setup



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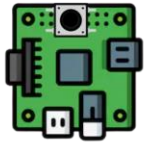


node_sancus2

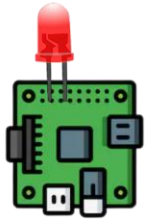
Deployment & configuration of the modules and their connections

deployer

node_sgx

user

Setup



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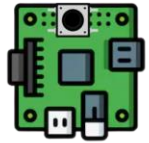


node_sancus2

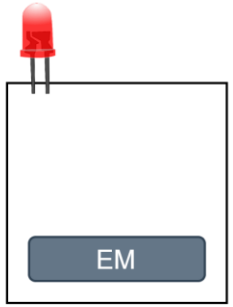
node_sgx

deployer

HTTP requests to get # of button presses

user

Deployment



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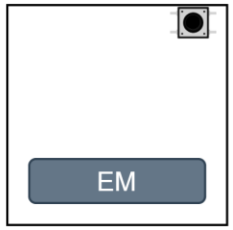

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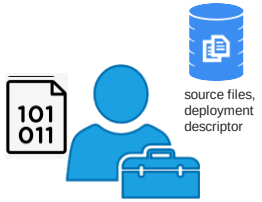

deployer

user

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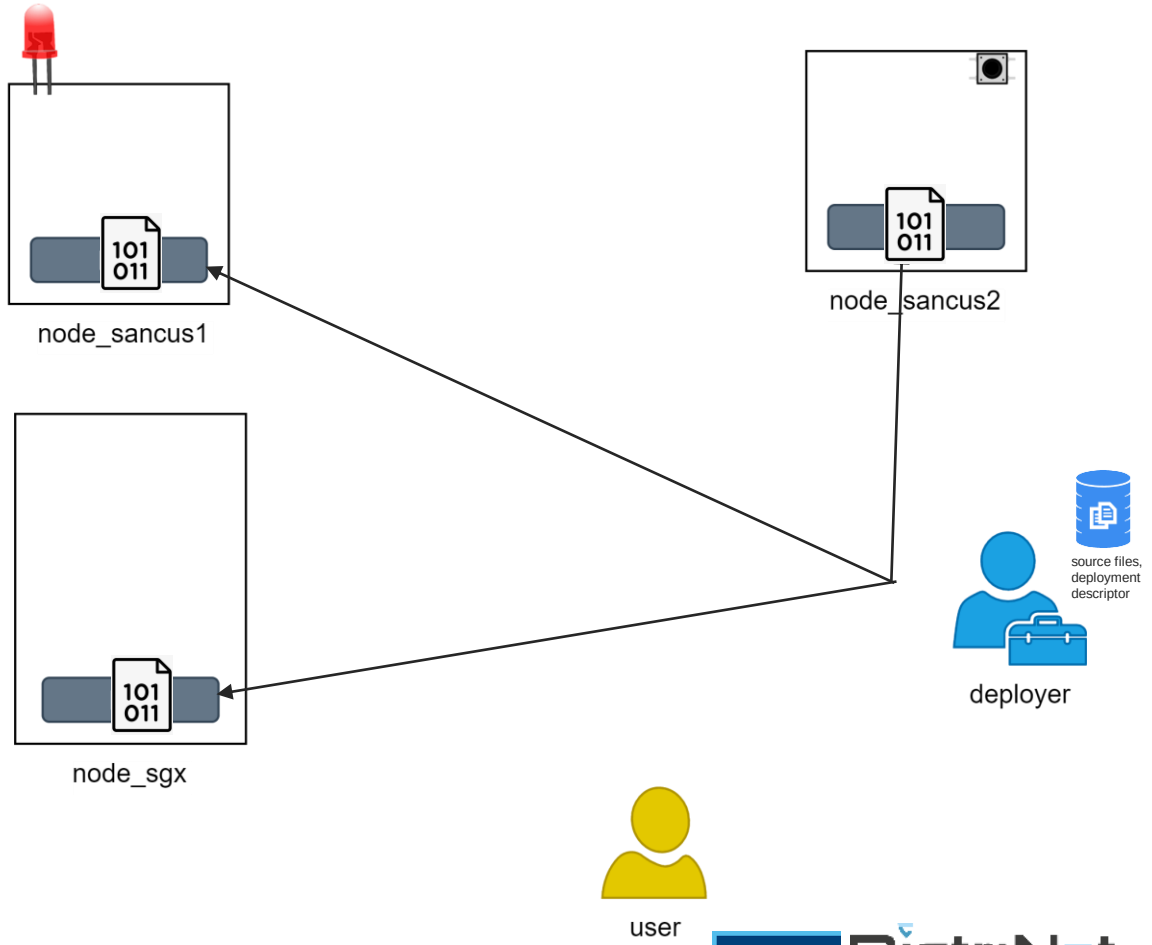
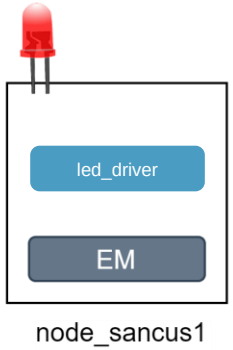
Deployment

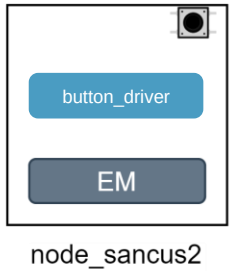
- Send binaries to nodes

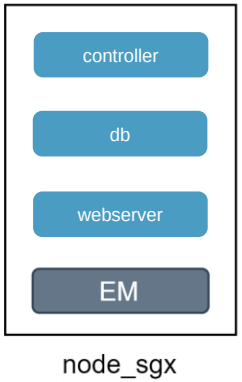


Deployment

- Send binaries to nodes
- Load modules







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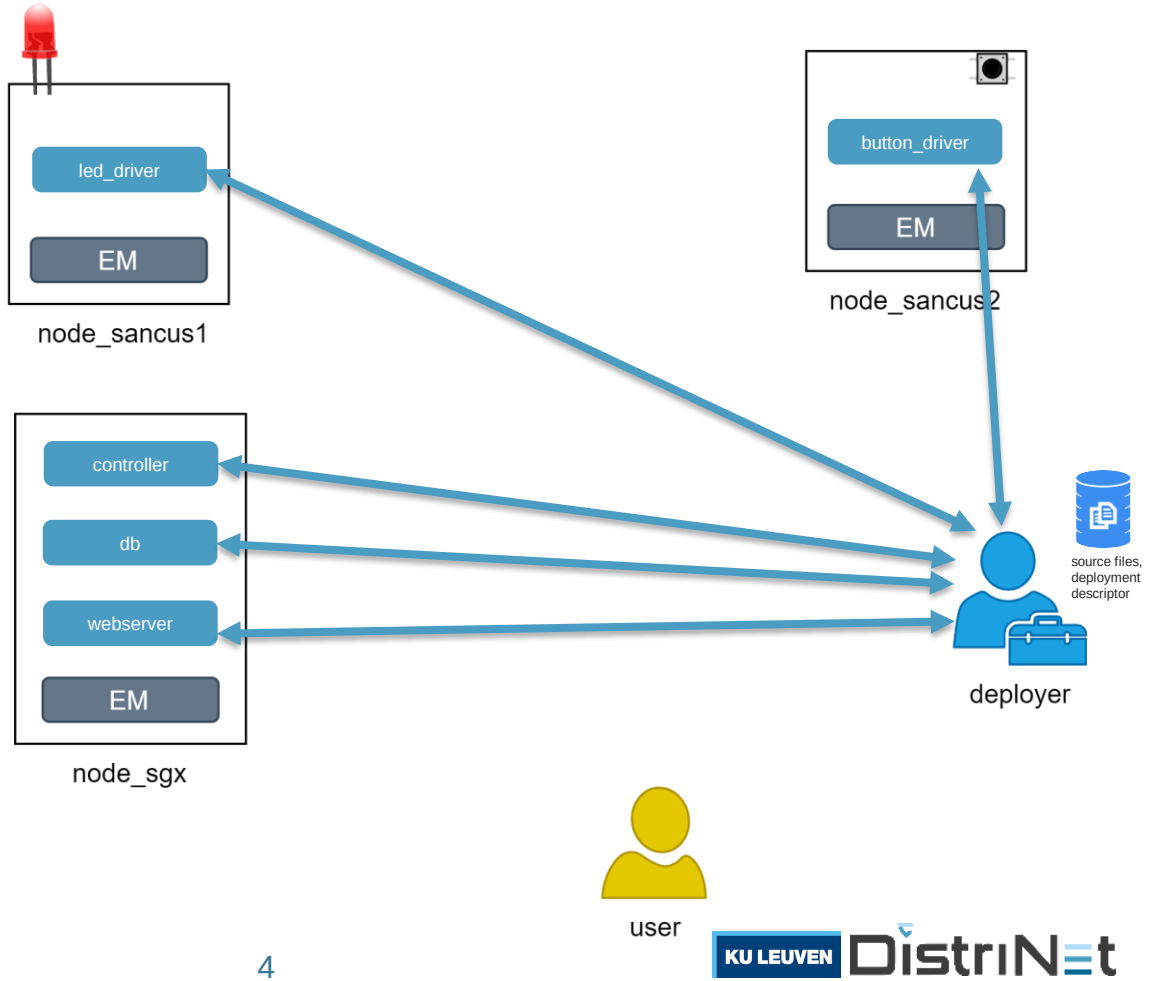
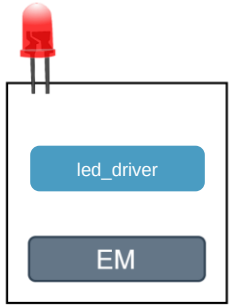
Deployment

- Send binaries to nodes
- Load modules
- Remote Attestation
  - Establishment of secure channels using module keys



Establishment of connections



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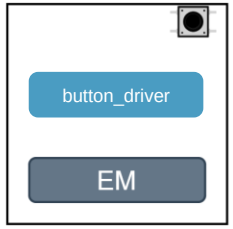
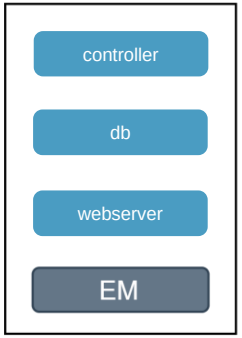


node_sancus2



node_sgx

deployer

user

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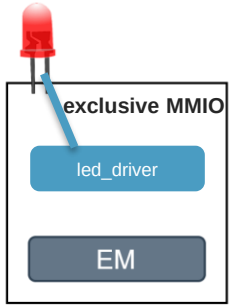

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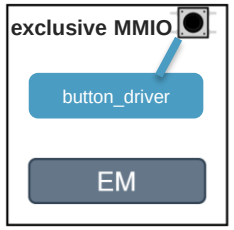
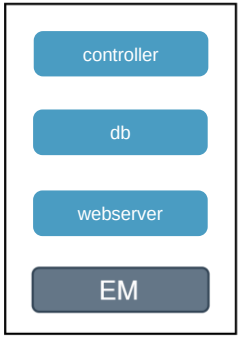


node_sancus2



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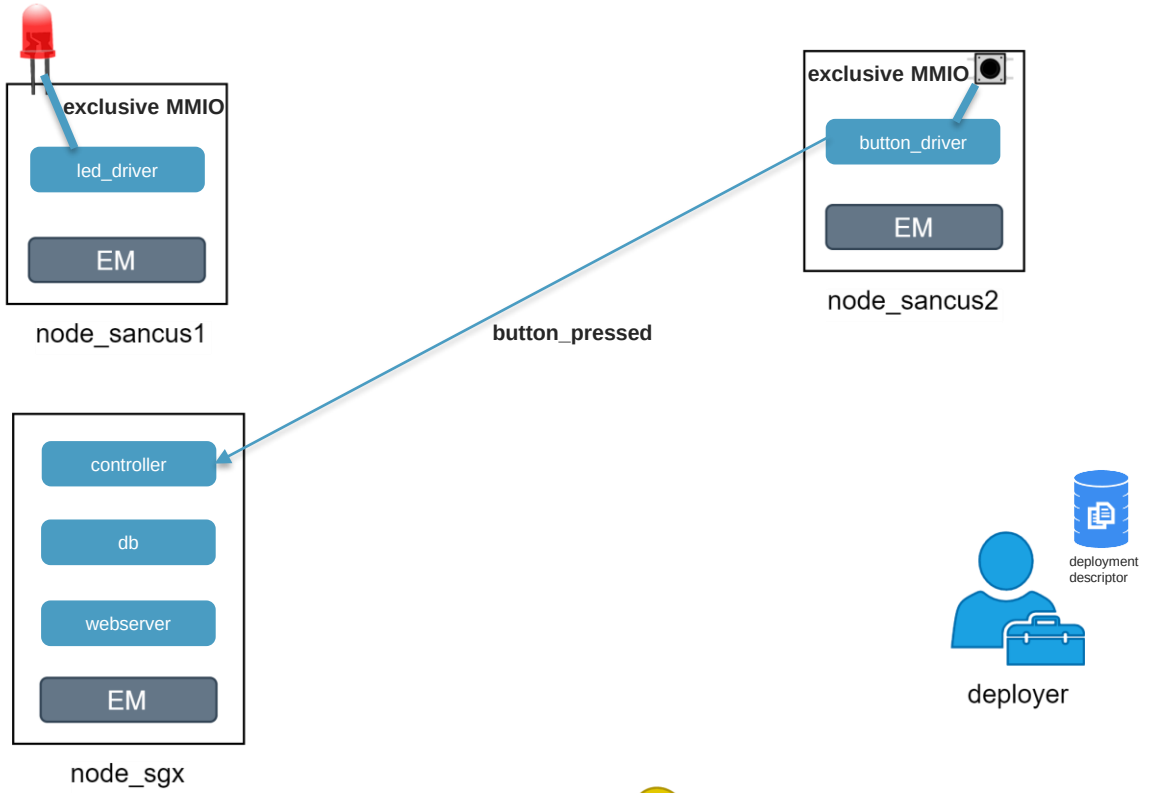

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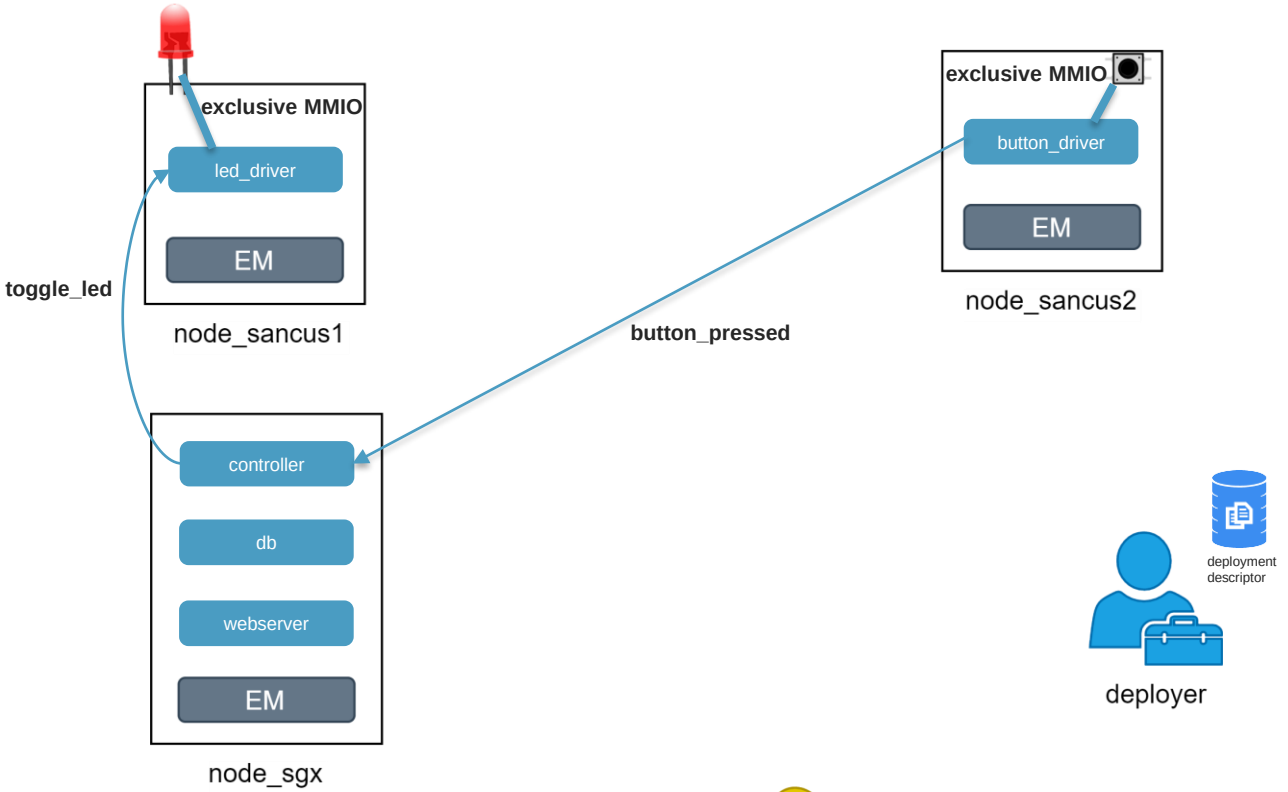

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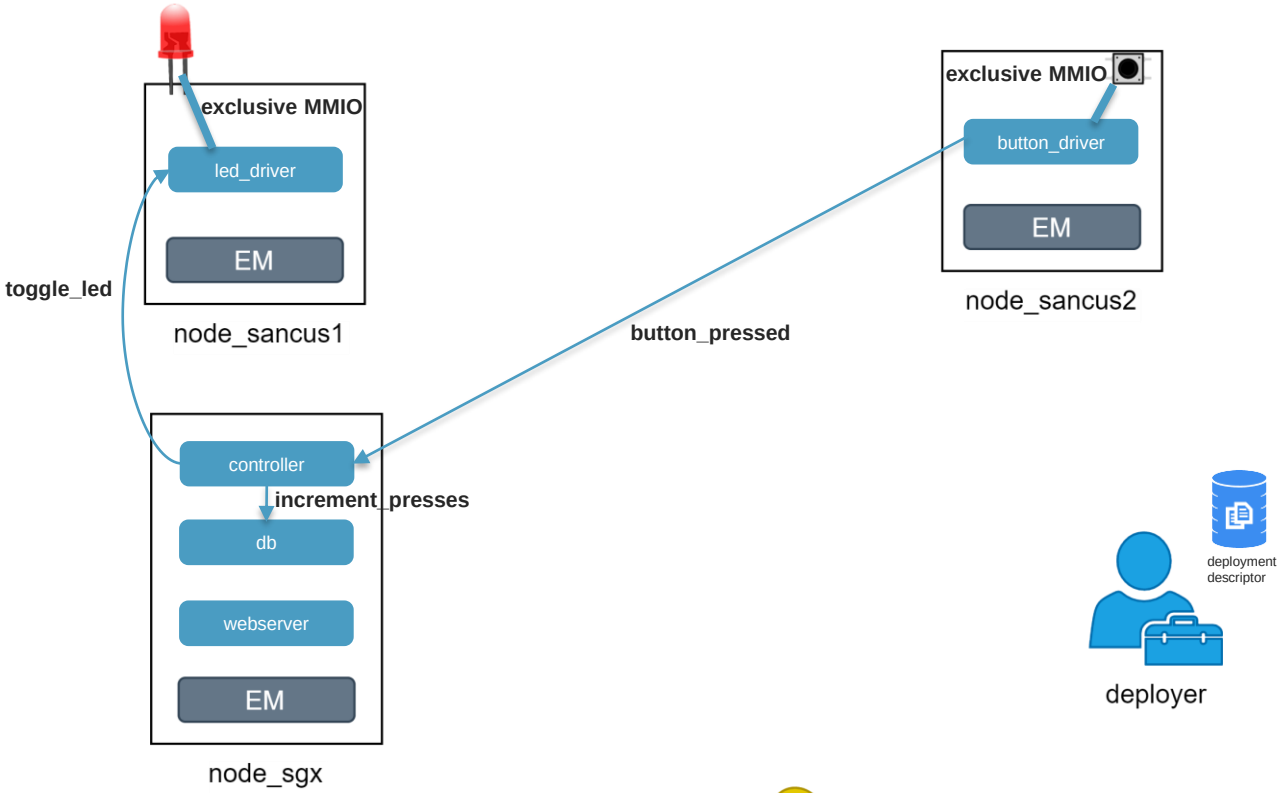

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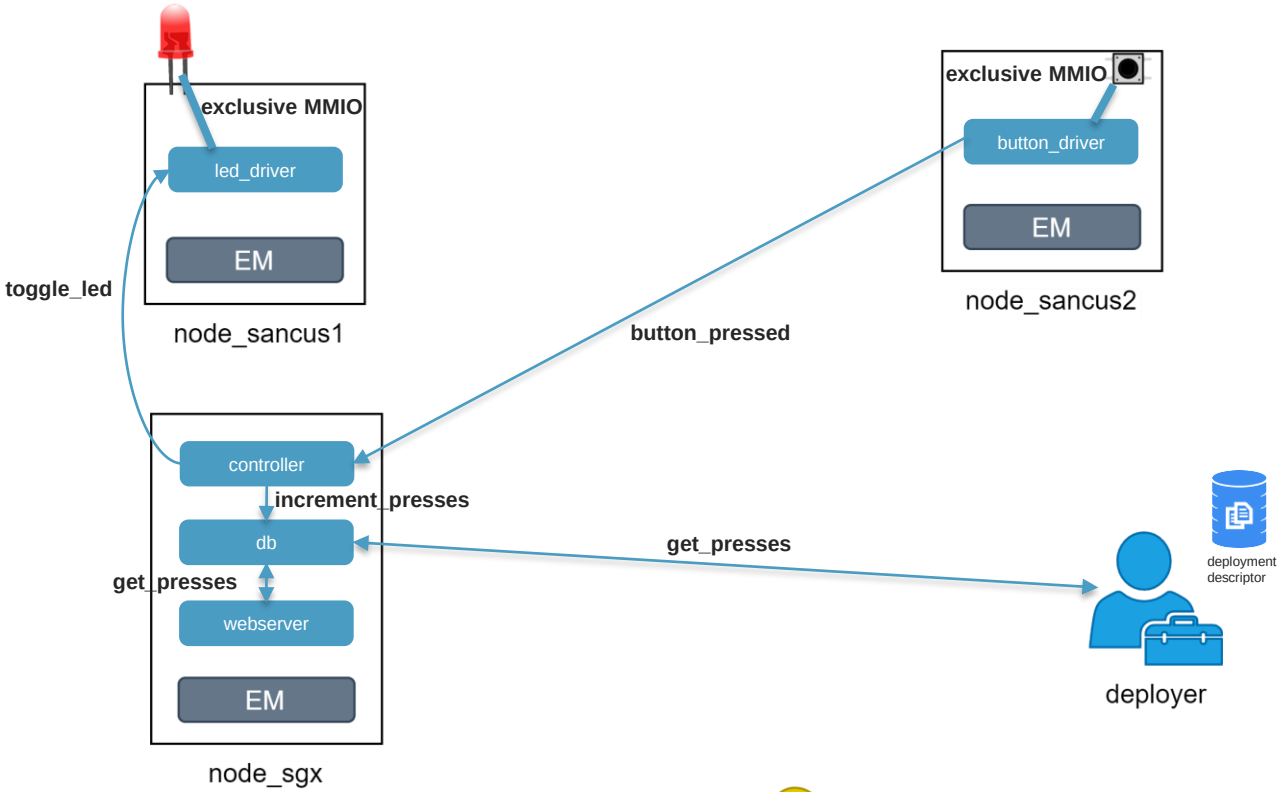

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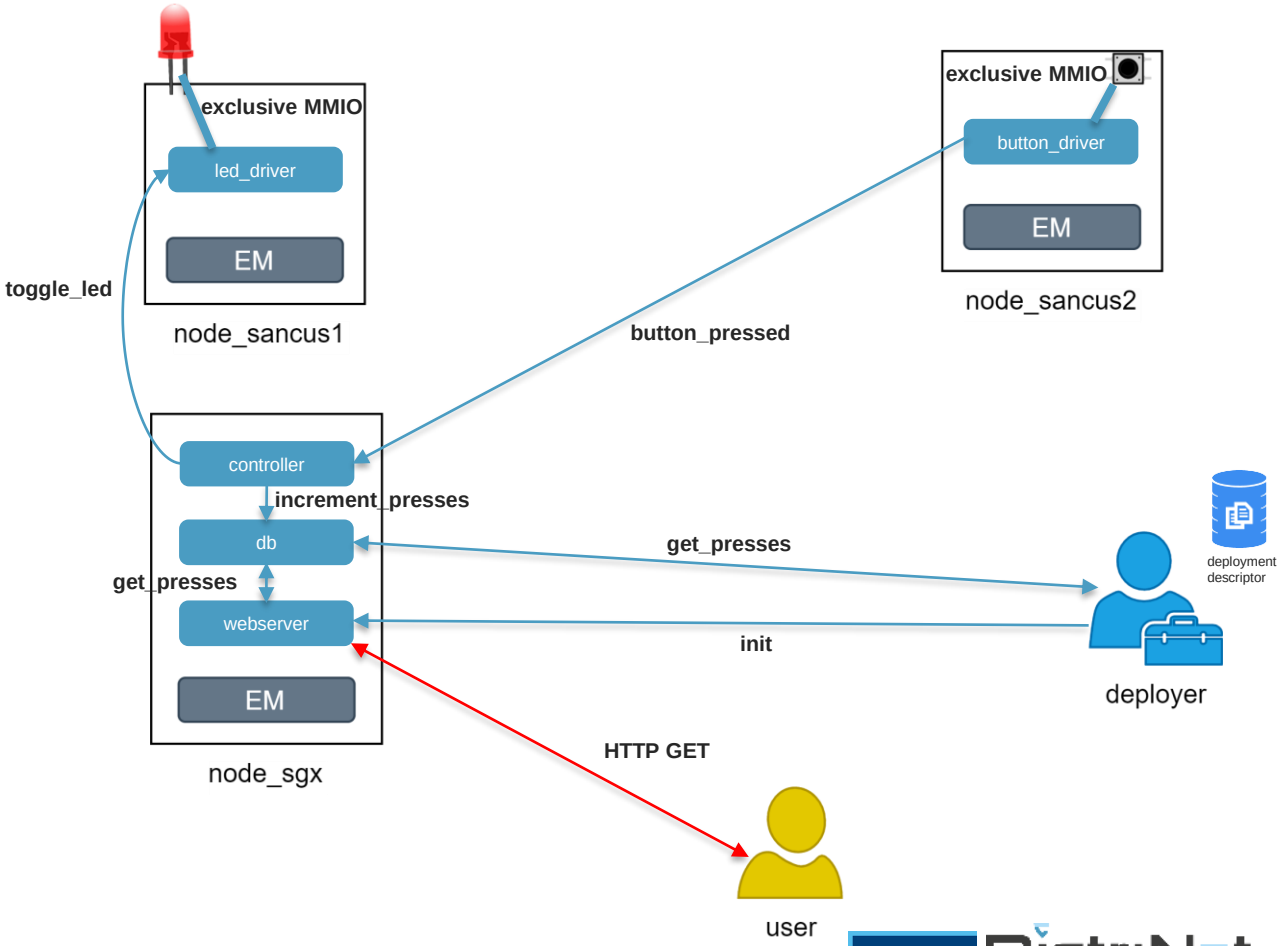

Source code snippet: controller

```
○ ○ ○

//@ sm_output(toggle_led)
//@ sm_output(increment_presses)

//@sm_input
pub fn button_pressed(_data : &[u8]) {
    info!("Remote button has been pressed");

    // toggle LED
    toggle_led(&[]);

    // increment occurrences on db
    increment_presses(&[]);
}
```

Deployment descriptor snippet: connections

```
"connections": [
    {
        "from_module": "button_driver",
        "from_output": "button_pressed",
        "to_module": "controller",
        "to_input": "button_pressed",
        "encryption": "spongent"
    },
    {
        "name": "init-server",
        "direct": true,
        "to_module": "webserver",
        "to_input": "init",
        "encryption": "aes"
    }
]
```

Demo!

github.com/gianlu33/authentic-execution

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Security discussion

- Strong **integrity**
  - The LED can be **only** toggled by a button press
  - The value stored in the db can be **only** incremented by a button press

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  - TEEs
  - Secure communication channels

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- **Confidentiality** of application state and sensitive data
  - TEEs
  - Secure communication channels
- Availability out of scope
  - nothing happens if, e.g., an event is lost

Future work

TrustZone support

- available soon
- with Rust

More flexible deployment tools

- stop/migrate a module
- deploy new modules after first deployment

SGX improvements

- Remote Attestation using Fortanix CCM
- performance
- sealing

Thank you!

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