Discussion on Scalable AP-TEE for RISC-V

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Trusted Computing SIG meeting

Outline (initial discussion from 11-23-2021)

- **What is a TEE?**
- **What use cases do TEEs enable - what threats do they address?**
  - **Hosted cloud (multi-tenancy, operators)**
  - **Edge platform (untrusted physical environment)**
  - **Multi-party compute (privacy-oriented use cases)**
  - **Client platforms (IP-protection, remote workers)**
- **Security requirements of a TEE (vis-a-vis the above use cases)**
- **Attestation Standards**

Discussion on 1-4-2022:

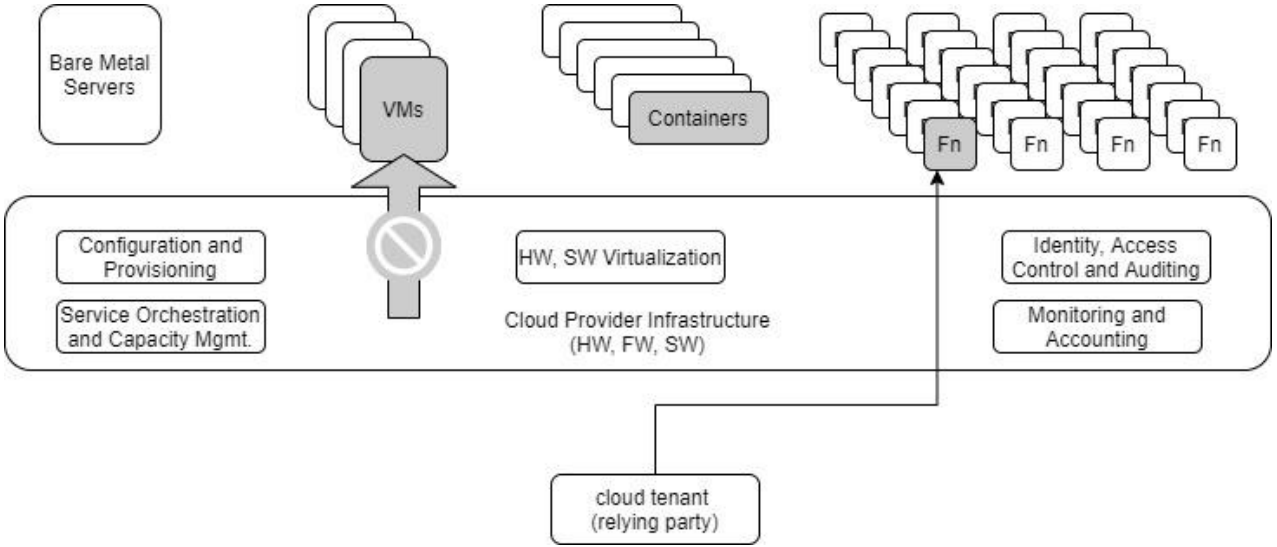
- **Goals**
- **Threat Model**

Trusted Execution Environment

A TEE enables isolated workloads on an application processor (or accelerator), where a hardware-attestable trusted computing base (TCB) enforces confidentiality and integrity of assets loaded within the trusted execution environment.

Use Cases

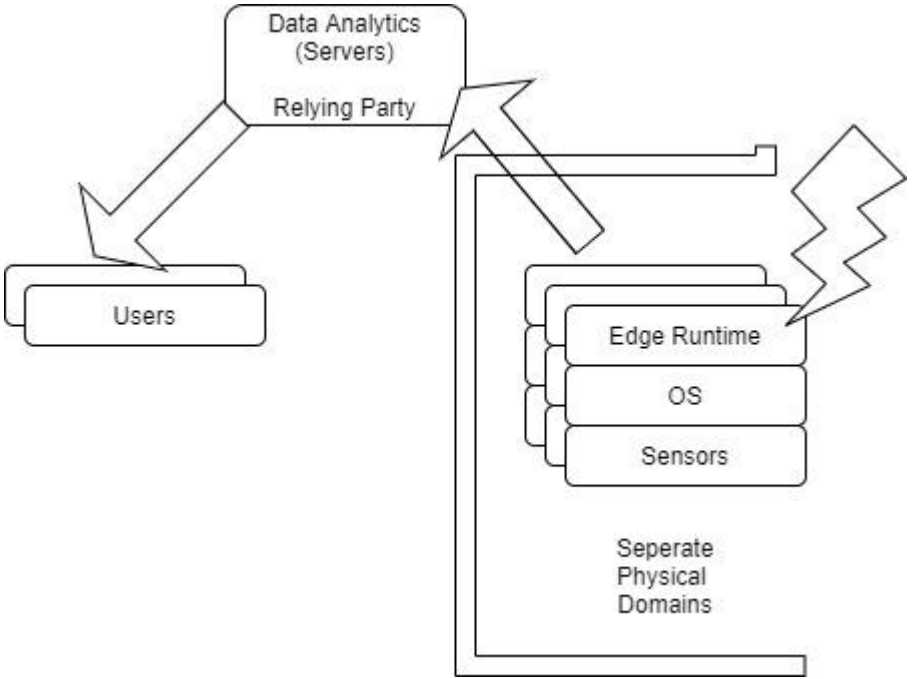
Multi-tenant hosted cloud environment



Unauthorized entities may include anyone with physical access to the hardware, including system administrators, the infrastructure owner, cloud service providers, the host firmware, operating system and hypervisor, other applications and devices on the host.

Use Cases

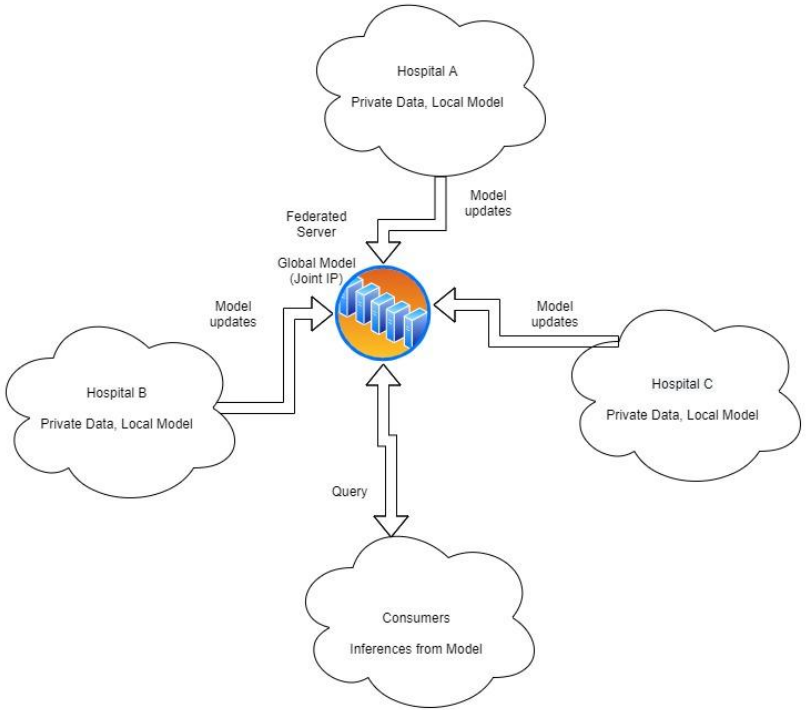
Edge cloud, IOT-based data analytics require TEE to preserve data integrity



Edge cloud and (IoT) devices are generally deemed to be under constant threat of malicious physical access.

Use Cases

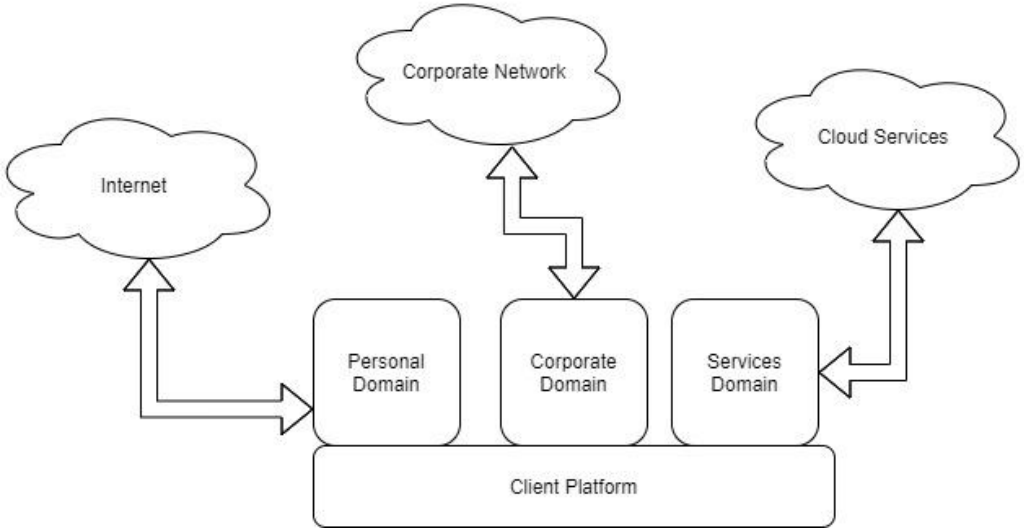
Multi-party computation on CPU/Accelerators



Multiple entities aggregating their proprietary privacy-sensitive data and collaboratively analyzing it to gain new insights (also privacy-sensitive)

Use Cases

Client Platforms, Automotive, Multi-domain Platforms



Computing devices used to separate roles (trust domains) - e.g. personal/corporate, automotive

Analyze data and build models on the device to reduce the need for off-device processing

Security Requirements (high-level)

- Isolation
- Confidentiality
- Integrity
- Authentication
- HW-rooted TCB
  - Attestation
  - Recovery
  - Updates
- No Dos from tenants

Non-security requirements - DoS from platform host, availability -> RAS/functional goal?

Opens/Notes/Feedback from 11-23-2021 RVI discussion

- We should provide security targets in terms of common criteria protection profiles
- Add/expand on the multi-domain use case 4 to describe mixed-criticality domains (automotive for e.g.)
- Describe function isolation (storage, networking etc) in the multi-tenant use case
- Add non-circumvention to the high level security requirements (done)
- Clarify that availability is a functional requirement for RAS, QoS - not a security requirement (done)

Standards, Interoperability

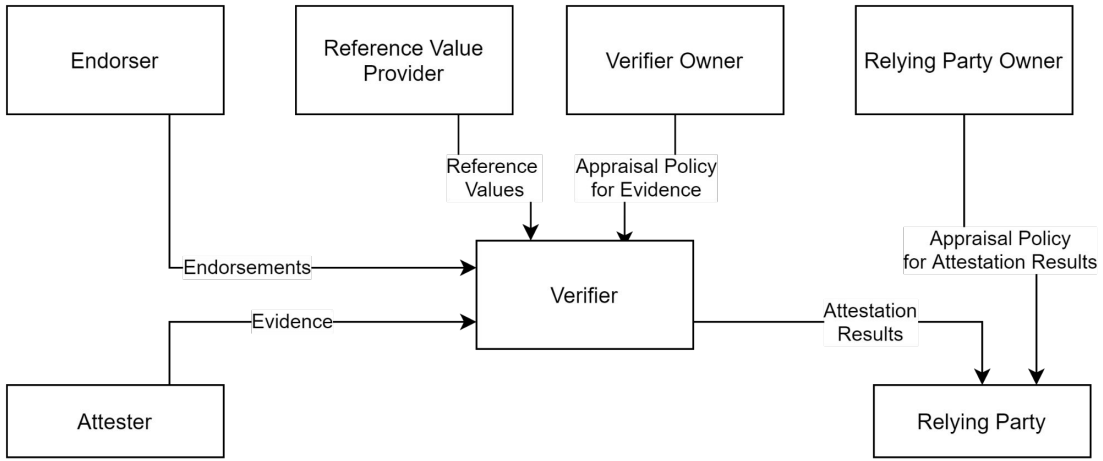
IETF Remote AttesTation procedures (RATS)

TCG Device Identifier Composition Engine (DICE)

DMTF Security Protocol and Data Model (SPDM)

OpenEnclave SDK

ARM Veraison



Outline (follow-on discussions)

Discussion on 1-4-2022:

- **Goals**
- **Threat Model**

Goals

- Primary: Meet a high security bar for workload confidentiality
  - See adversary and threat model on next slides

- Accommodate App, VM, container, other SW deployment models within TEEs
- Minimize software refactoring (for workloads)
- Avoid (new) ISA complexity
- Be able to accommodate future ISA extensions
- Leverage attestation standards, frameworks
- Provide line of sight to Confidential IO, migration, snapshot, TCB updates and plan for addressing evolving threats
- Ensure requirements are met for Data-Center, Automotive, Edge, IOT and other use cases

Threat Model Discussion

Adversary Model

Current priority

System Software adversary - This includes system software executing in M-mode as well as S- and HS-modes. Such an adversary can access privileged CSRs, all of system memory, CPU registers and IO devices that can be programmed to access system resources (memory and other devices).

Simple Hardware adversary - This includes adversaries that can use hardware attacks such as bus interposers to snoop on memory/device interfaces, which may give the adversary the ability to tamper with data in memory.

Advanced Hardware adversary - This includes adversaries that can use advanced hardware attacks, with unlimited physical access to the devices, and use mechanisms to tamper with the hardware TCB e.g., extract keys from hardware, using capabilities such as scanning electron microscopes, fib attacks, glitching attacks etc. (this adversary is secondary priority)

*Note - U-mode SW adversary privilege-escalation prevention is expected to be a function of the System software, hence not listed here, and is addressed by other efforts e.g. CFI SIG. If U-mode can escalate privilege, it is equivalent to System SW adversary.

Threats

Terminology - TVM: TEE VM (a confidential workload example); TSM: TEE Security Monitor (a TCB element enforcing the confidentiality of TVMs)

T1: Loss of confidentiality of TVM and TSM memory via in-scope adversaries that may **read TSM/TVM memory via CPU accesses**

T2: Tamper/content-injection to TVM and TSM memory from in-scope adversaries that may **modify TSM/TVM memory via CPU side accesses**

T3: Tamper of TVM/TSM memory from in-scope adversaries via **software-induced row-hammer attacks on memory**

T4: Malicious injection of content into TSM/TVM execution context using **physical memory aliasing attacks via system firmware adverary**

T5: Information leakage of workload data **via read of CPU registers, CSRs** via in-scope adversaries

T6: Incorrect execution of workload via **runtime modification of CPU registers**, CSRs, mode switches via in-scope adversaries

T7: Invalid code execution or data injection/replacement via **second-level paging remap attacks** via system software adversary

T8: **Malicious asynchronous interrupt injection** or denied leading to information leakage or incorrect execution of the TEE

T9: **Malicious hardware mtime register manipulation** or manipulation of time read from the time CSR causing invalid execution of TVM to lead to information loss

T10: Loss of Confidentiality **via DMA access from devices under adversary control** e.g. via manipulation of IOMMU programming

T11: Loss of Confidentiality **via DMA access from devices assigned to a TVM**. Devices bound to a TVM must enforce similar properties as the TEE on the SOC.

T12: Content injection, exfiltration or replay (within and across TEE memory) **via hardware approaches, including via exposed interface/links** to other CPU sockets, memory and/or devices assigned to a TVM

T13: **Downgrading TEE TCB elements** (example M-mode firmware, TSM) to older versions or loading Invalid TEE TCB elements on the platform to enable confidentiality, integrity attacks

T14: **Leveraging transient execution side-channel attacks** to leak confidential data e.g. via shared caches, branch predictor poisoning, page-faults.

T15: **Leveraging architectural side-channel attacks** due to shared cache and other shared resources e.g. via prime/probe, flush/reload approaches

T16: **Malicious access to ciphertext with known plaintext** to launch a dictionary attack on a TVM to extract confidential data.

T17: **Tamper of TVM state during migration** of a TEE workload from one platform to another.

T18: **Forging attestation reports** from the RoT

T19: **Stale TLB translations** (for U/HS mode or for VU/VS) created during TSM or TVM operations are used to execute malicious code in the TVM (or consume stale/invalid data)

T20: **Unexpected enabling of performance monitoring and/or debug** on a TVM leading to information loss via performance monitoring events/counters and debug mode accessible information.

T21: A **TVM causes a denial of service** on the platform