Trusted Execution Environment Provisioning (TEEP) Architecture
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Abstract

A Trusted Execution Environment (TEE) is designed to provide a hardware-isolation mechanism to separate a regular operating system from security-sensitive application components.

This architecture document motivates the design and standardization of a protocol for managing the lifecycle of trusted applications running inside a TEE.

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1. Introduction

Applications executing in a device are exposed to many different attacks intended to compromise the execution of the application, or reveal the data upon which those applications are operating. These attacks increase with the number of other applications on the device, with such other applications coming from potentially untrustworthy sources. The potential for attacks further increase with the complexity of features and applications on devices, and the unintended interactions among those features and applications. The danger of attacks on a system increases as the sensitivity of the applications or data on the device increases. As an example, exposure of emails from a mail client is likely to be of concern to
its owner, but a compromise of a banking application raises even greater concerns.

The Trusted Execution Environment (TEE) concept is designed to execute applications in a protected environment that separates applications inside the TEE from the regular operating system and from other applications on the device. This separation reduces the possibility of a successful attack on application components and the data contained inside the TEE. Typically, application components are chosen to execute inside a TEE because those application components perform security sensitive operations or operate on sensitive data. An application component running inside a TEE is referred to as a Trusted Application (TA), while a normal application running in the regular operating system is referred to as an Untrusted Application (UA).

The TEE uses hardware to enforce protections on the TA and its data, but also presents a more limited set of services to applications inside the TEE than is normally available to UA’s running in the normal operating system.

But not all TEEs are the same, and different vendors may have different implementations of TEEs with different security properties, different features, and different control mechanisms to operate on TAs. Some vendors may themselves market multiple different TEEs with different properties attuned to different markets. A device vendor may integrate one or more TEEs into their devices depending on market needs.

To simplify the life of developers and service providers interacting with TAs in a TEE, an interoperable protocol for managing TAs running in different TEEs of various devices is needed. In this TEE ecosystem, there often arises a need for an external trusted party to verify the identity, claims, and rights of Service Providers (SP), devices, and their TEEs. This trusted third party is the Trusted Application Manager (TAM).

This protocol addresses the following problems:

- A Service Provider (SP) intending to provide services through a TA to users of a device needs to determine security-relevant information of a device before provisioning their TA to the TEE within the device. Examples include the verification of the device ‘root of trust’ and the type of TEE included in a device.

- A TEE in a device needs to determine whether a Service Provider (SP) that wants to manage a TA in the device is authorized to manage TAs in the TEE, and what TAs the SP is permitted to manage.
- The parties involved in the protocol must be able to attest that a TEE is genuine and capable of providing the security protections required by a particular TA.

- A Service Provider (SP) must be able to determine if a TA exists (is installed) on a device (in the TEE), and if not, install the TA in the TEE.

- A Service Provider (SP) must be able to check whether a TA in a device’s TEE is the most up-to-date version, and if not, update the TA in the TEE.

- A Service Provider (SP) must be able to remove a TA in a device’s TEE if the SP is no longer offering such services or the services are being revoked from a particular user (or device). For example, if a subscription or contract for a particular service has expired, or a payment by the user has not been completed or has been rescinded.

- A Service Provider (SP) must be able to define the relationship between cooperating TAs under the SP’s control, and specify whether the TAs can communicate, share data, and/or share key material.

2. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

The following terms are used:

- Client Application: An application running in a Rich Execution Environment, such as an Android, Windows, or iOS application. We sometimes refer to this as the ‘Client App’.

- Device: A physical piece of hardware that hosts a TEE along with a Rich Execution Environment. A Device contains a default list of Trust Anchors that identify entities (e.g., TAMs) that are trusted by the Device. This list is normally set by the Device Manufacturer, and may be governed by the Device’s network carrier. The list of Trust Anchors is normally modifiable by the Device’s owner or Device Administrator. However the Device manufacturer and network carrier may restrict some modifications, for example, by not allowing the manufacturer or carrier’s Trust Anchor to be removed or disabled.
- Rich Execution Environment (REE): An environment that is provided and governed by a typical OS (e.g., Linux, Windows, Android, iOS), potentially in conjunction with other supporting operating systems and hypervisors; it is outside of the TEE. This environment and applications running on it are considered un-trusted.

- Service Provider (SP): An entity that wishes to provide a service on Devices that requires the use of one or more Trusted Applications. A Service Provider requires the help of a TAM in order to provision the Trusted Applications to remote devices.

- Device User: A human being that uses a device. Many devices have a single device user. Some devices have a primary device user with other human beings as secondary device users (e.g., parent allowing children to use their tablet or laptop). Relates to Device Owner and Device Administrator.

- Device Owner: A device is always owned by someone. It is common for the (primary) device user to also own the device, making the device user/owner also the device administrator. In enterprise environments it is more common for the enterprise to own the device, and device users have no or limited administration rights. In this case, the enterprise appoints a device administrator that is not the device owner.

- Device Administrator (DA): An entity that is responsible for administration of a Device, which could be the device owner. A Device Administrator has privileges on the Device to install and remove applications and TAs, approve or reject Trust Anchors, and approve or reject Service Providers, among possibly other privileges on the Device. A Device Administrator can manage the list of allowed TAMS by modifying the list of Trust Anchors on the Device. Although a Device Administrator may have privileges and Device-specific controls to locally administer a device, the Device Administrator may choose to remotely administrate a device through a TAM.

- Trust Anchor: A public key in a device whose corresponding private key is held by an entity implicitly trusted by the device. The Trust Anchor may be a certificate or it may be a raw public key along with additional data if necessary such as its public key algorithm and parameters. The Trust Anchor is normally stored in a location that resists unauthorized modification, insertion, or replacement. The digital fingerprint of a Trust Anchor may be stored along with the Trust Anchor certificate or public key. A device can use the fingerprint to uniquely identify a Trust Anchor. The Trust Anchor private key owner can sign certificates of other public keys, which conveys trust about those keys to the
device. A certificate signed by the Trust Anchor communicates that the private key holder of the signed certificate is trusted by the Trust Anchor holder, and can therefore be trusted by the device. Trust Anchors in a device may be updated by an authorized party when a Trust Anchor should be deprecated or a new Trust Anchor should be added.

- **Trusted Application (TA):** An application component that runs in a TEE.

- **Trusted Execution Environment (TEE):** An execution environment that runs alongside of, but is isolated from, an REE. A TEE has security capabilities and meets certain security-related requirements. It protects TEE assets from general software attacks, defines rigid safeguards as to data and functions that a program can access, and resists a set of defined threats. It should have at least the following three properties:
  
  (a) A device unique credential that cannot be cloned;

  (b) Assurance that only authorized code can run in the TEE;

  (c) Memory that cannot be read by code outside the TEE.

There are multiple technologies that can be used to implement a TEE, and the level of security achieved varies accordingly.

- **Root-of-Trust (RoT):** A hardware or software component in a device that is inherently trusted to perform a certain security-critical function. A RoT should be secure by design, small, and protected by hardware against modification or interference. Examples of RoTs include software/firmware measurement and verification using a Trust Anchor (RoT for Verification), provide signed assertions using a protected attestation key (RoT for Reporting), or protect the storage and/or use of cryptographic keys (RoT for Storage). Other RoTs are possible, including RoT for Integrity, and RoT for Measurement. Reference: NIST SP800-164 (Draft).

- **Trusted Firmware (TFW):** A firmware in a device that can be verified with a Trust Anchor by RoT for Verification.

- **Bootloader key:** This symmetric key is protected by electronic fuse (eFUSE) technology. In this context it is used to decrypt a TFW private key, which belongs to a device-unique private/public key pair. Not every device is equipped with a bootloader key.

This document uses the following abbreviations:
3. Assumptions

This specification assumes that an applicable device is equipped with one or more TEEs and each TEE is pre-provisioned with a device-unique public/private key pair, which is securely stored.

A TEE uses an isolation mechanism between Trusted Applications to ensure that one TA cannot read, modify or delete the data and code of another TA.

4. Use Cases

4.1. Payment

A payment application in a mobile device requires high security and trust about the hosting device. Payments initiated from a mobile device can use a Trusted Application to provide strong identification and proof of transaction.

For a mobile payment application, some biometric identification information could also be stored in a TEE. The mobile payment application can use such information for authentication.

A secure user interface (UI) may be used in a mobile device to prevent malicious software from stealing sensitive user input data. Such an application implementation often relies on a TEE for user input protection.
4.2. Authentication

For better security of authentication, a device may store its sensitive authentication keys inside a TEE, providing hardware-protected security key strength and trusted code execution.

4.3. Internet of Things

The Internet of Things (IoT) has been posing threats to networks and national infrastructures because of existing weak security in devices. It is very desirable that IoT devices can prevent malware from manipulating actuators (e.g., unlocking a door), or stealing or modifying sensitive data such as authentication credentials in the device. A TEE can be the best way to implement such IoT security functions.

TEEs could be used to store variety of sensitive data for IoT devices. For example, a TEE could be used in smart door locks to store a user’s biometric information for identification, and for protecting access the locking mechanism.

4.4. Confidential Cloud Computing

A tenant can store sensitive data in a TEE in a cloud computing server such that only the tenant can access the data, preventing the cloud hosting provider from accessing the data. A tenant can run TAs inside a server TEE for secure operation and enhanced data security. This provides benefits not only to tenants with better data security but also to cloud hosting provider for reduced liability and increased cloud adoption.

5. Architecture

5.1. System Components

The following are the main components in the system. Full descriptions of components not previously defined are provided below. Interactions of all components are further explained in the following paragraphs.
Service Providers (SP) and Device Administrators (DA) utilize the services of a TAM to manage TAs on Devices. SPs do not directly interact with devices. DAs may elect to use a TAM for remote administration of TAs instead of managing each device directly.

TAM: A TAM is responsible for performing lifecycle management activity on TA’s and SD’s on behalf of Service Providers and Device Administrators. This includes creation and deletion of TA’s and SD’s, and may include, for example, over-the-air updates to keep an SP’s TAs up-to-date and clean up when a version should be removed. TAMs may provide services that make it easier for SPs or DAs to use the TAM’s service to manage multiple devices, although that is not required of a TAM.

The TAM performs its management of TA’s and SD’s through an interaction with a Device’s TEEP Broker. As shown in #notionalarch, the TAM cannot directly contact a Device, but must wait for a the TEEP Broker or a Client Application to contact the TAM requesting a particular service. This architecture is intentional in order to accommodate network and application firewalls that normally protect user and enterprise devices from arbitrary connections from external network entities.

A TAM may be publicly available for use by many SPs, or a TAM may be private, and accessible by only one or a limited number of SPs.
It is expected that manufacturers and carriers will run their own private TAM. Another example of a private TAM is a TAM running as a Software-as-a-Service (SaaS) within an SP.

A SP or Device Administrator chooses a particular TAM based on whether the TAM is trusted by a Device or set of Devices. The TAM is trusted by a device if the TAM’s public key is an authorized Trust Anchor in the Device. A SP or Device Administrator may run their own TAM, however the Devices they wish to manage must include this TAM’s public key in the Trust Anchor list.

A SP or Device Administrator is free to utilize multiple TAMs. This may be required for a SP to manage multiple different types of devices from different manufacturers, or devices on different carriers, since the Trust Anchor list on these different devices may contain different TAMs. A Device Administrator may be able to add their own TAM’s public key or certificate to the Trust Anchor list on all their devices, overcoming this limitation.

Any entity is free to operate a TAM. For a TAM to be successful, it must have its public key or certificate installed in Devices Trust Anchor list. A TAM may set up a relationship with device manufacturers or carriers to have them install the TAM’s keys in their device’s Trust Anchor list. Alternatively, a TAM may publish its certificate and allow Device Administrators to install the TAM’s certificate in their devices as an after-market-action.

- TEEP Broker: The TEEP Broker is an application running in a Rich Execution Environment that enables the message protocol exchange between a TAM and a TEE in a device. The TEEP Broker does not process messages on behalf of a TEE, but merely is responsible for relaying messages from the TAM to the TEE, and for returning the TEE’s responses to the TAM.

A Client Application is expected to communicate with a TAM to request TAs that it needs to use. The Client Application needs to pass the messages from the TAM to TEEs in the device. This calls for a component in the REE that Client Applications can use to pass messages to TEEs. An Agent is thus an application in the REE or software library that can relay messages from a Client Application to a TEE in the device. A device usually comes with only one active TEE. A TEE may provide such an Agent to the device manufacturer to be bundled in devices. Such a TEE must also include an Agent counterpart, namely, a processing module inside the TEE, to parse TAM messages sent through the Agent. An Agent is generally acting as a dummy relaying box with just the TEE interacting capability; it doesn’t need and shouldn’t parse protocol messages.
- Certification Authority (CA): Certificate-based credentials used for authenticating a device, a TAM and an SP. A device embeds a list of root certificates (Trust Anchors), from trusted CAs that a TAM will be validated against. A TAM will remotely attest a device by checking whether a device comes with a certificate from a CA that the TAM trusts. The CAs do not need to be the same; different CAs can be chosen by each TAM, and different device CAs can be used by different device manufacturers.

5.2. Different Renditions of TEEP Architecture

There is nothing prohibiting a device from implementing multiple TEEs. In addition, some TEEs (for example, SGX) present themselves as separate containers within memory without a controlling manager within the TEE. In these cases, the rich operating system hosts multiple TEEP brokers, where each broker manages a particular TEE or set of TEEs. Enumeration and access to the appropriate broker is up to the rich OS and the applications. Verification that the correct TA has been reached then becomes a matter of properly verifying TA attestations, which are unforgeable. The multiple TEE approach is shown in the diagram below. For brevity, TEEP Broker 2 is shown interacting with only one TAM and UA, but no such limitation is intended to be implied in the architecture.
In the diagram above, TEEP Broker 1 controls interactions with the TA’s in TEE-1, and TEEP Broker 2 controls interactions with the TA’s in TEE-2. This presents some challenges for a TAM in completely managing the device, since a TAM may not interact with all the TEEP Brokers on a particular platform. In addition, since TEE’s may be physically separated, with wholly different resources, there may be no need for TEEP Brokers to share information on installed TAs or resource usage. However, the architecture guarantees that the TAM will receive all the relevant information from the TEEP Broker to which it communicates.

5.3. Multiple TAMs and Relationship to TAs

As shown in Figure 2, the TEEP Broker provides connections from the TEE and the Client App to one or more TAMs. The selection of which TAM to communicate with is dependent on information from the Client App and is directly related to the TA.
When a SP offers a service which requires a TA, the SP associates that service with a specific TA. The TA itself is digitally signed, protecting its integrity, but the signature also links the TA back to the signer. The signer is usually the SP, but in some cases may be another party that the SP trusts. The SP selects one or more TAMs through which to offer their service, and communicates the information of the service and the specific client apps and TAs to the TAM.

The SP chooses TAMs based upon the markets into which the TAM can provide access. There may be TAMs that provide services to specific types of mobile devices, or mobile device operating systems, or specific geographical regions or network carriers. A SP may be motivated to utilize multiple TAMs for its service in order to maximize market penetration and availability on multiple types of devices. This likely means that the same service will be available through multiple TAMs.

When the SP publishes the Client App to an app store or other app repositories, the SP binds the Client App with a manifest that identifies what TAMs can be contacted for the TA. In some situations, an SP may use only a single TAM - this is likely the case for enterprise applications or SPs serving a closed community. For broad public apps, there will likely be multiple TAMs in the manifest - one servicing one brand of mobile device and another servicing a different manufacturer, etc. Because different devices and different manufacturers trust different TAMs, the manifest will include different TAMs that support this SP’s client app and TA. Multiple TAMs allow the SP to provide their service and this app (and TA) to multiple different devices.

When the TEEP Broker receives a request to contact the TAM for a Client App in order to install a TA, a list of TAMs may be provided. The TEEP Broker selects a single TAM that is consistent with the list of trusted TAMs (trust anchors) provisioned on the device. For any client app, there should be only a single TAM for the TEEP Broker to contact. This is also the case when a Client App uses multiple TAs, or when one TA depends on another TA in a software dependency (see section TBD). The reason is that the SP should provide each TAM that it places in the Client App’s manifest all the TAs that the app requires. There is no benefit to going to multiple different TAMs, and there is no need for a special TAM to be contacted for a specific TA.

[Note: This should always be the case. When a particular device or TEE supports only a special proprietary attestation mechanism, then a specific TAM will be needed that supports that attestation scheme. The TAM should also support standard attestation signatures as well.]
It is highly unlikely that a set of TAs would use different proprietary attestation mechanisms since a TEE is likely to support only one such proprietary scheme.]

[Note: This situation gets more complex in situations where a Client App expects another application or a device to already have a specific TA installed. This situation does not occur with SGX, but could occur in situations where the secure world maintains an trusted operating system and runs an entire trusted system with multiple TAs running. This requires more discussion.]

5.4. Client Apps, Trusted Apps, and Personalization Data

In TEEP, there is an explicit relationship and dependence between the client app in the REE and one or more TAs in the TEE, as shown in Figure 2. From the perspective of a device user, a client app that uses one or more TA’s in a TEE appears no different from any other untrusted application in the REE. However, the way the client app and its corresponding TA’s are packaged, delivered, and installed on the device can vary. The variations depend on whether the client app and TA are bundled together or are provided separately, and this has implications to the management of the TAs in the TEE. In addition to the client app and TA, the TA and/or TEE may require some additional data to personalize the TA to the service provider or the device user. This personalization data is dependent on the TEE, the TA and the SP; an example of personalization data might be username and password of the device user’s account with the SP, or a secret symmetric key used to by the TA to communicate with the SP. The personalization data must be encrypted to preserve the confidentiality of potentially sensitive data contained within it. Other than this requirement to support confidentiality, TEEP place no limitations or requirements on the personalization data.

There are three possible cases for bundling of the Client App, TA, and personalization data:

1. The Client App, TA, and personalization data are all bundled together in a single package by the SP and provided to the TEEP Broker through the TAM.

2. The Client App and the TA are bundled together in a single binary, which the TAM or a publicly accessible app store maintains in repository, and the personalization data is separately provided by the SP. In this case, the personalization data is collected by the TAM and included in the InstallTA message to the TEEP Broker.
3. All components are independent. The device user installs the Client App through some independent or device-specific mechanism, and the TAM provides the TA and personalization data from the SP. Delivery of the TA and personalization data may be combined or separate.

5.5. Examples of Application Delivery Mechanisms in Existing TEEs

In order to better understand these cases, it is helpful to review actual implementations of TEEs and their application delivery mechanisms.

In Intel Software Guard Extensions (SGX), the Client App and TA are typically bound into the same binary (Case 2). The TA is compiled into the Client App binary using SGX tools, and exists in the binary as a shared library (.so or .dll). The Client App loads the TA into an SGX enclave when the client needs the TA. This organization makes it easy to maintain compatibility between the Client App and the TA, since they are updated together. It is entirely possible to create a Client App that loads an external TA into an SGX enclave and use that TA (Case 3). In this case, the Client App would require a reference to an external file or download such a file dynamically, place the contents of the file into memory, and load that as a TA. Obviously, such file or downloaded content must be properly formatted and signed for it to be accepted by the SGX TEE. In SGX, for Case 2 and Case 3, the personalization data is normally loaded into the SGX enclave (the TA) after the TA has started. Although Case 1 is possible with SGX, there are no instances of this known to be in use at this time, since such a construction would required a special installation program and SGX TA to recieve the encrypted binary, decrypt it, separate it into the three different elements, and then install all three. This installation is complex, because the Client App decrypted inside the TEE must be passed out of the TEE to an installer in the REE which would install the Client App; this assumes that the Client App binary includes the TA code also, otherwise there is a significant problem in getting the SGX enclave code (the TA) from the TEE, through the installer and into the Client App in a trusted fashion. Finally, the personalization data would need to be sent out of the TEE (encrypted in an SGX enclave-to-enclave manner) to the REE’s installation app, which would pass this data to the installed Client App, which would in turn send this data to the SGX enclave (TA). This complexity is due to the fact that each SGX enclave is separate and does not have direct communication to one another.

[NOTE: Need to add an equivalent discussion for an ARM/TZ implementation]
5.6. TEEP Architectural Support for Client App, TA, and Personalization Data Delivery

This section defines TEEP support for the three different cases for delivery of the Client App, TA, and personalization data.

[Note: discussion of format of this single binary, and who/what is responsible for splitting these things apart, and installing the client app into the REE, the TA into the TEE, and the personalization data into the TEE or TA. Obviously the decryption must be done by the TEE but this may not be supported by all TAs.]

5.7. Entity Relations

This architecture leverages asymmetric cryptography to authenticate a device to a TAM. Additionally, a TEE in a device authenticates a TAM and TA signer. The provisioning of Trust Anchors to a device may differ from one use case to the other. A device administrator may want to have the capability to control what TAs are allowed. A device manufacturer enables verification of the TA signers and TAM providers; it may embed a list of default Trust Anchors that the signer of an allowed TA’s signer certificate should chain to. A device administrator may choose to accept a subset of the allowed TAs via consent or action of downloading.

```
PKI    CA    -- CA    CA --
|    |    |             |
|    |    |             |
|    |    |             |
|    ---   Agent / Client App   --- |
|    |    |             |
|    |    |             |
Device SW    --- TEE TAM------
|    |    |             |
|    |    |             |
|    |    |             |
|    -- FW

Figure 3: Entities
```
Figure 4: Developer Experience

Figure 4 shows an application developer building two applications: 1) a rich Client Application; 2) a TA that provides some security functions to be run inside a TEE. At step 2, the application developer uploads the Client Application (2a) to an Application Store. The Client Application may optionally bundle the TA binary. Meanwhile, the application developer may provide its TA to a TAM provider that will be managing the TA in various devices. 3. A user will go to an Application Store to download the Client Application. The Client Application will trigger TA installation by initiating communication with a TAM. This is the step 4. The Client Application will get messages from TAM, and interacts with device TEE via an Agent.

The following diagram shows a system diagram about the entity relationships between CAs, TAMs, SPs and devices.
In the previous diagram, different CAs can be used for different types of certificates. Messages are always signed, where the signer key is the message originator’s private key such as that of a TAM, the private key of trusted firmware (TFW), or a TEE’s private key.

The main components consist of a set of standard messages created by a TAM to deliver device SD and TA management commands to a device, and device attestation and response messages created by a TEE that responds to a TAM’s message.

It should be noted that network communication capability is generally not available in TAs in today’s TEE-powered devices. The networking functionality must be delegated to a rich Client Application. Client Applications will need to rely on an agent in the REE to interact with a TEE for message exchanges. Consequently, a TAM generally communicates with a Client Application about how it gets messages that originate from a TEE inside a device. Similarly, a TA or TEE generally gets messages from a TAM via some Client Application, namely, an agent in this protocol architecture, not directly from the network.
It is imperative to have an interoperable protocol to communicate with different TAMs and different TEEs in different devices. This is the role of the agent, which is a software component that bridges communication between a TAM and a TEE. The agent does not need to know the actual content of messages except for the TEE routing information.

5.8. Trust Anchors in TEE

Each TEE comes with a trust store that contains a whitelist of Trust Anchors that are used to validate a TAM’s certificate. A TEE will accept a TAM to create new Security Domains and install new TAs on behalf of an SP only if the TAM’s certificate is chained to one of the root CA certificates in the TEE’s trust store.

A TEE’s trust store is typically preloaded at manufacturing time. It is out of the scope in this document to specify how the trust anchors should be updated when a new root certificate should be added or existing one should be updated or removed. A device manufacturer is expected to provide its TEE trust anchors live update or out-of-band update to Device Administrators.

When trust anchor update is carried out, it is imperative that any update must maintain integrity where only authentic trust anchor list from a device manufacturer or a Device Administrator is accepted. This calls for a complete lifecycle flow in authorizing who can make trust anchor update and whether a given trust anchor list are non-tampered from the original provider. The signing of a trust anchor list for integrity check and update authorization methods are desirable to be developed. This can be addressed outside of this architecture document.

Before a TAM can begin operation in the marketplace to support a device with a particular TEE, it must obtain a TAM certificate from a CA that is listed in the trust store of the TEE.

5.9. Trust Anchors in TAM

The Trust Anchor store in a TAM consists of a list of CA certificates that sign various device TEE certificates. A TAM will accept a device for TA management if the TEE in the device uses a TEE certificate that is chained to a CA that the TAM trusts.

5.10. Keys and Certificate Types

This architecture leverages the following credentials, which allow delivering end-to-end security without relying on any transport security.
<table>
<thead>
<tr>
<th>Key Entity Name</th>
<th>Location</th>
<th>Issuer</th>
<th>Checked Against</th>
<th>Cardinality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. TFW key pair and certificate</td>
<td>Device secure storage</td>
<td>FW CA</td>
<td>A whitelist of FW root CA trusted by TAMs</td>
<td>1 per device</td>
</tr>
<tr>
<td>2. TEE key pair and certificate</td>
<td>Device TEE</td>
<td>TEE CA under a root CA</td>
<td>A whitelist of TEE root CA trusted by TAMs</td>
<td>1 per device</td>
</tr>
<tr>
<td>3. TAM key pair and certificate</td>
<td>TAM provider</td>
<td>TAM CA under a root CA</td>
<td>A whitelist of TAM root CA embedded in TEE</td>
<td>1 or multiple can be used by a TAM</td>
</tr>
<tr>
<td>4. SP key pair and certificate</td>
<td>SP SP signer CA</td>
<td>SP signer CA</td>
<td>A SP uses a TAM. TA is signed by a SP signer. TEE delegates trust of TA to TAM. SP signer is associated with an SD as the owner.</td>
<td>1 or multiple can be used by a TAM</td>
</tr>
</tbody>
</table>

**Figure 6: Key and Certificate Types**

1. **TFW key pair and certificate:** A key pair and certificate for evidence of trustworthy firmware in a device. This key pair is optional for TEEP architecture. Some TEE may present its trusted attributes to a TAM using signed attestation with a TFW key. For example, a platform that uses a hardware based TEE can have attestation data signed by a hardware protected TFW key.
   - **Location:** Device secure storage
   - **Supported Key Type:** RSA and ECC
   - **Issuer:** OEM CA
   - **Checked Against:** A whitelist of FW root CA trusted by TAMs
   - **Cardinality:** One per device
2. TEE key pair and certificate: It is used for device attestation to a remote TAM and SP.
   - This key pair is burned into the device by the device manufacturer. The key pair and its certificate are valid for the expected lifetime of the device.
   - Location: Device TEE
   - Supported Key Type: RSA and ECC
   - Issuer: A CA that chains to a TEE root CA
   - Checked Against: A whitelist of TEE root CAs trusted by TAMs
   - Cardinality: One per device

3. TAM key pair and certificate: A TAM provider acquires a certificate from a CA that a TEE trusts.
   - Location: TAM provider
   - Supported Key Type: RSA and ECC.
   - Supported Key Size: RSA 2048-bit, ECC P-256 and P-384. Other sizes should be anticipated in future.
   - Issuer: TAM CA that chains to a root CA
   - Checked Against: A whitelist of TAM root CAs embedded in a TEE
   - Cardinality: One or multiple can be used by a TAM

4. SP key pair and certificate: An SP uses its own key pair and certificate to sign a TA.
   - Location: SP
   - Supported Key Type: RSA and ECC
   - Supported Key Size: RSA 2048-bit, ECC P-256 and P-384. Other sizes should be anticipated in future.
   - Issuer: An SP signer CA that chains to a root CA
   - Checked Against: An SP uses a TAM. A TEE trusts an SP by validating trust against a TAM that the SP uses. A TEE trusts a TAM to ensure that a TA is trustworthy.
5.11. Scalability

This architecture uses a PKI. Trust Anchors exist on the devices to enable the TEE to authenticate TAMs, and TAMs use Trust Anchors to authenticate TEEs. Since a PKI is used, many intermediate CA certificates can chain to a root certificate, each of which can issue many certificates. This makes the protocol highly scalable. New factories that produce TEEs can join the ecosystem. In this case, such a factory can get an intermediate CA certificate from one of the existing roots without requiring that TAMs are updated with information about the new device factory. Likewise, new TAMs can join the ecosystem, providing they are issued a TAM certificate that chains to an existing root whereby existing TEEs will be allowed to be personalized by the TAM without requiring changes to the TEE itself. This enables the ecosystem to scale, and avoids the need for centralized databases of all TEEs produced or all TAMs that exist.

5.12. Message Security

Messages created by a TAM are used to deliver device SD and TA management commands to a device, and device attestation and messages created by the device TEE to respond to TAM messages.

These messages are signed end-to-end and are typically encrypted such that only the targeted device TEE or TAM is able to decrypt and view the actual content.

5.13. Security Domain Hierarchy and Ownership

The primary job of a TAM is to help an SP to manage its trusted applications. A TA is typically installed in an SD. An SD is commonly created for an SP.

When an SP delegates its SD and TA management to a TAM, an SD is created on behalf of a TAM in a TEE and the owner of the SD is assigned to the TAM. An SD may be associated with an SP but the TAM has full privilege to manage the SD for the SP.

Each SD for an SP is associated with only one TAM. When an SP changes TAM, a new SP SD must be created to associate with the new TAM. The TEE will maintain a registry of TAM ID and SP SD ID mapping.

From an SD ownership perspective, the SD tree is flat and there is only one level. An SD is associated with its owner. It is up to the
TEE implementation how it maintains SD binding information for a TAM and different SPs under the same TAM.

It is an important decision in this architecture that a TEE doesn’t need to know whether a TAM is authorized to manage the SD for an SP. This authorization is implicitly triggered by an SP Client Application, which instructs what TAM it wants to use. An SD is always associated with a TAM in addition to its SP ID. A rogue TAM isn’t able to do anything on an unauthorized SP’s SD managed by another TAM.

Since a TAM may support multiple SPs, sharing the same SD name for different SPs creates a dependency in deleting an SD. An SD can be deleted only after all TAs associated with the SD are deleted. An SP cannot delete a Security Domain on its own with a TAM if a TAM decides to introduce such sharing. There are cases where multiple virtual SPs belong to the same organization, and a TAM chooses to use the same SD name for those SPs. This is totally up to the TAM implementation and out of scope of this specification.

5.14. SD Owner Identification and TAM Certificate Requirements

There is a need of cryptographically binding proof about the owner of an SD in a device. When an SD is created on behalf of a TAM, a future request from the TAM must present itself as a way that the TEE can verify it is the true owner. The certificate itself cannot reliably used as the owner because TAM may change its certificate.

** need to handle the normal key roll-over case, as well as the less frequent key compromise case

To this end, each TAM will be associated with a trusted identifier defined as an attribute in the TAM certificate. This field is kept the same when the TAM renew its certificates. A TAM CA is responsible to vet the requested TAM attribute value.

This identifier value must not collide among different TAM providers, and one TAM shouldn’t be able to claim the identifier used by another TAM provider.

The certificate extension name to carry the identifier can initially use SubjectAltName:registeredID. A dedicated new extension name may be registered later.

One common choice of the identifier value is the TAM’s service URL. A CA can verify the domain ownership of the URL with the TAM in the certificate enrollment process.
A TEE can assign this certificate attribute value as the TAM owner ID for the SDs that are created for the TAM.

An alternative way to represent an SD ownership by a TAM is to have a unique secret key upon SD creation such that only the creator TAM is able to produce a proof-of-possession (PoP) data with the secret.

5.15. Service Provider Container

A sample Security Domain hierarchy for the TEE is shown in Figure 7.

```
----
|  TEE  |
----
   ----
|  ---|
    ----
       | SP1 SD1 |
          ----
       |  ---|
            ----
               | SP1 SD2 |
                  ----
               |  ---|
                    ----
                       | SP2 SD1 |
                           ----
```

Figure 7: Security Domain Hierarchy

The architecture separates SDs and TAs such that a TAM can only manage or retrieve data for SDs and TAs that it previously created for the SPs it represents.

5.16. A Sample Device Setup Flow

Step 1: Prepare Images for Devices

1. [TEE vendor] Deliver TEE Image (CODE Binary) to device OEM
2. [CA] Deliver root CA Whitelist
3. [Soc] Deliver TFW Image

Step 2: Inject Key Pairs and Images to Devices

1. [OEM] Generate TFW Key Pair (May be shared among multiple devices)
2. [OEM] Flash signed TFW Image and signed TEE Image onto devices (signed by TFW Key)
Step 3: Set up attestation key pairs in devices

1. [OEM] Flash TFW Public Key and a bootloader key.
2. [TFW/TEE] Generate a unique attestation key pair and get a certificate for the device.

Step 4: Set up Trust Anchors in devices

1. [TFW/TEE] Store the key and certificate encrypted with the bootloader key
2. [TEE vendor or OEM] Store trusted CA certificate list into devices

6. TEEP Broker

A TEE and TAs do not generally have the capability to communicate to the outside of the hosting device. For example, GlobalPlatform [GPTEE] specifies one such architecture. This calls for a software module in the REE world to handle the network communication. Each Client Application in the REE might carry this communication functionality but such functionality must also interact with the TEE for the message exchange.

The TEE interaction will vary according to different TEEs. In order for a Client Application to transparently support different TEEs, it is imperative to have a common interface for a Client Application to invoke for exchanging messages with TEEs.

A shared agent comes to meet this need. An agent is an application running in the REE of the device or an SDK that facilitates communication between a TAM and a TEE. It also provides interfaces for Client Applications to query and trigger TA installation that the application needs to use.

It isn’t always that a Client Application directly calls such an agent to interact with a TEE. A REE Application Installer might carry out TEE and TAM interaction to install all required TAs that a Client Application depends. A Client Application may have a metadata file that describes the TAs it depends on and the associated TAM that each TA installation goes to use. The REE Application Installer can inspect the application metadata file and installs TAs on behalf of the Client Application without requiring the Client Application to run first.

This interface for Client Applications or Application Installers may be commonly an OS service call for an REE OS. A Client Application
or an Application Installer interacts with the device TEE and the TAMs.

6.1. Role of the Agent

An agent abstracts the message exchanges with the TEE in a device. The input data is originated from a TAM or the first initialization call to trigger a TA installation.

The agent may internally process a message from a TAM. At least, it needs to know where to route a message, e.g., TEE instance. It does not need to process or verify message content.

The agent returns TEE / TFW generated response messages to the caller. The agent is not expected to handle any network connection with an application or TAM.

The agent only needs to return an agent error message if the TEE is not reachable for some reason. Other errors are represented as response messages returned from the TEE which will then be passed to the TAM.

6.2. Agent Implementation Consideration

A Provider should consider methods of distribution, scope and concurrency on devices and runtime options when implementing an agent. Several non-exhaustive options are discussed below. Providers are encouraged to take advantage of the latest communication and platform capabilities to offer the best user experience.

6.2.1. Agent Distribution

The agent installation is commonly carried out at OEM time. A user can dynamically download and install an agent on-demand.

It is important to ensure a legitimate agent is installed and used. If an agent is compromised it may drop messages and thereby introduce a denial of service.

6.2.2. Number of Agents

We anticipate only one shared agent instance in a device. The device's TEE vendor will most probably supply one agent.

With one shared agent, the agent provider is responsible to allow multiple TAMs and TEE providers to achieve interoperability. With a
standard agent interface, each TAM can implement its own SDK for its
SP Client Applications to work with this agent.

Multiple independent agent providers can be used as long as they have
standard interface to a Client Application or TAM SDK. Only one
agent is expected in a device.

TAM providers are generally expected to provide an SDK for SP
applications to interact with an agent for the TAM and TEE
interaction.

7. Attestation

Attestation is the process through which one entity (an attestor)
presents a series of claims to another entity (a verifier), and
provides sufficient proof that the claims are true. Different
verifiers may have different standards for attestation proofs and not
all attestations are acceptable to every verifier. TEEP attestations
are based upon the use of an asymmetric key pair under the control of
the TEE to create digital signatures across a well-defined claim set.

In TEEP, the primary purpose of an attestation is to allow a device
to prove to TAMS and SPs that a TEE in the device has particular
properties, was built by a particular manufacturer, or is executing
a particular TA. Other claims are possible; this architecture
specification does not limit the attestation claims, but defines a
minimal set of claims required for TEEP to operate properly.
Extensions to these claims are possible, but are not defined in the
TEEP specifications. Other standards or groups may define the format
and semantics of extended claims. The TEEP specification defines the
claims format such that these extended claims may be easily included
in a TEEP attestation message.

As of the writing of this specification, device and TEE attestations
have not been standardized across the market. Different devices,
manufacturers, and TEEs support different attestation algorithms and
mechanisms. In order for TEEP to be inclusive, the attestation
format shall allow for both proprietary attestation signatures, as
well as a standardized form of attestation signature. Either form of
attestation signature may be applied to a set of TEEP claims, and both
forms of attestation shall be considered conformant with TEEP.
However, it should be recognized that not all TAMs or SPs may be able
to process all proprietary forms of attestations. All TAMs and SPs
MUST be able to process the TEEP standard attestation format and
attached signature.

The attestation formats and mechanisms described and mandated by TEEP
shall convey a particular set of cryptographic properties based on
minimal assumptions. The cryptographic properties are conveyed by the attestation; however the assumptions are not conveyed within the attestation itself.

The assumptions which may apply to an attestation have to do with the quality of the attestation and the quality and security provided by the TEE, the device, the manufacturer, or others involved in the device or TEE ecosystem. Some of the assumptions that might apply to an attestations include (this may not be a comprehensive list):

- Assumptions regarding the security measures a manufacturer takes when provisioning keys into devices/TEEs;
- Assumptions regarding what hardware and software components have access to the Attestation keys of the TEE;
- Assumptions related to the source or local verification of claims within an attestation prior to a TEE signing a set of claims;
- Assumptions regarding the level of protection afforded to attestation keys against exfiltration, modification, and side channel attacks;
- Assumptions regarding the limitations of use applied to TEE Attestation keys;
- Assumptions regarding the processes in place to discover or detect TEE breeches; and
- Assumptions regarding the revocation and recovery process of TEE attestation keys.

TAMs and SPs must be comfortable with the assumptions that are inherently part of any attestation they accept. Alternatively, any TAM or SP may choose not to accept an attestation generated from a particular manufacturer or device’s TEE based on the inherent assumptions. The choice and policy decisions are left up to the particular TAM/SP.

Some TAMs or SPs may require additional claims in order to properly authorize a device or TEE. These additional claims may help clear up any assumptions for which the TAM/SP wants to alleviate. The specific format for these additional claims are outside the scope of this specification, but the OTrP protocol SHALL allow these additional claims to be included in the attestation messages.

The following sub-sections define the cryptographic properties conveyed by the TEEP attestation, the basic set of TEEP claims.
required in a TEEP attestation, the TEEP attestation flow between the TAM the device TEE, and some implementation examples of how an attestation key may be realized in a real TEEP device.

7.1. Attestation Cryptographic Properties

The attestation constructed by TEEP must convey certain cryptographic properties from the attester to the verifier; in the case of TEEP, the attestation must convey properties from the device to the TAM and/or SP. The properties required by TEEP include:

- Non-repudiation, Unique Proof of Source - the cryptographic digital signature across the attestation, and optionally along with information in the attestation itself SHALL uniquely identify a specific TEE in a specific device.

- Integrity of claims - the cryptographic digital signature across the attestation SHALL cover the entire attestation including all meta data and all the claims in the attestation, ensuring that the attestation has not been modified since the TEE signed the attestation.

Standard public key algorithms such as RSA and ECDSA digital signatures convey these properties. Group public key algorithms such as EPID can also convey these properties, if the attestation includes a unique device identifier and an identifier for the TEE. Other cryptographic operations used in other attestation schemes may also convey these properties.

The TEEP standard attestation format SHALL use one of the following digital signature formats:

- RSA-2048 with SHA-256 or SHA-384 in RSASSA-PKCS1-v1_5 or PSS format
- RSA-3072 with SHA-256 or SHA-384 in RSASSA-PKCS1-v1_5 or PSS format
- ECDSA-256 using NIST P256 curve using SHA-256
- ECDSA-384 using NIST P384 curve using SHA-384
- HashEdDSA using Ed25519 with SHA-512 (Ed25519ph in RFC8032) and context="TEEP Attestation"
- EdDSA using Ed448 with SHAK256 (Ed448ph in RFC8032) and context="TEEP Attestation"
All TAMs and SPs MUST be able to accept attestations using these algorithms, contingent on their acceptance of the assumptions implied by the attestations.

7.2. TEEP Attestation Structure

For a TEEP attestation to be useful, it must contain an information set allowing the TAM and/or SP to assess the attestation and make a related security policy decision. The structure of the TEEP attestation is shown in the diagram below.

```
+------(Signed By)---------+
|                           |
+---------------------------+
| Attestation Header        |
|  The Claims               |
|  The Attestation Signature(s) |
+----------------------------+
| +--------------------------+ |
| | V                        | |
| | V                        | |
| +--------------------------+ |
| +---------------------------+ |
| | Device Identifying Info   |
| |  | TEE Identifying Info     |
| |  | Liveness Operation Proof  |
| |  | Action or Operation Claims |
| |  | Ad optional Info          |
| +---------------------------+ |
```

Figure 8: Structure of TEEP Attestation

The Attestation Header SHALL identify the "Attestation Type" and the "Attestation Signature Type" along with an "Attestation Format Version Number." The "Attestation Type" identifies the minimal set of claims that MUST be included in the attestation; this is an identifier for a profile that defines the claims that should be included in the attestation as part of the "Action or Operation Specific Claims." The "Attestation Signature Type" identifies the type of attestation signature that is attached. The type of attestation signature SHALL be one of the standard signatures types identified by an IANA number, a proprietary signature type identified by an IANA number, or the generic "Proprietary Signature" with an accompanying proprietary identifier. Not all TAMs may be able to process proprietary signatures.

The claims in the attestation are set of mandatory and optional claims. The claims themselves SHALL be defined in an attestation claims dictionary. See the next section on TEEP Attestation Claims.
Claims are grouped in profiles under an identifier (Attestation Type), however all attestations require a minimal set of claims which includes:

- **Device Identifying Info**: TEEP attestations must uniquely identify a device to the TAM and SP. This identifier allows the TAM/SP to provide services unique to the device, such as managing installed TAs, and providing subscriptions to services, and locating device-specific keying material to communicate with or authenticate the device. Additionally, device manufacturer information must be provided to provide better universal uniqueness qualities without requiring globally unique identifiers for all devices.

- **TEE Identifying info**: The type of TEE that generated this attestation must be identified. Standard TEE types are identified by an IANA number, but also must include version identification information such as the hardware, firmware, and software version of the TEE, as applicable by the TEE type. Structure to the version number is required. TEE manufacturer information for the TEE is required in order to disambiguate the same TEE type created by different manufacturers and resolve potential assumptions around manufacturer provisioning, keying and support for the TEE.

- **Liveness Proof**: a claim that includes liveness information SHALL be included which may be a large nonce or may be a timestamp and short nonce.

- **Action Specific Claims**: Certain attestation types shall include specific claims. For example an attestation from a specific TA shall include a measurement, version and signing public key for the TA.

- **Additional Claims**: (Optional - May be empty set) A TAM or SP may require specific additional claims in order to address potential assumptions, such as the requirement that a device’s REE performed a secure boot, or that the device is not currently in a debug or non-productions state. A TAM may require a device to provide a device health attestation that may include some claims or measurements about the REE. These claims are TAM specific.

7.3. **TEEP Attestation Claims**

TEEP requires a set of attestation claims that provide sufficient evidence to the TAM and/or SP that the device and its TEE meet certain minimal requirements. Because attestation formats are not yet broadly standardized across the industry, standardization work is currently ongoing, and it is expected that extensions to the attestation claims will be required as new TEEs and devices are
created, the set of attestation claims required by TEEP SHALL be
defined in an IANA registry. That registry SHALL be defined in the
OTrP protocol with sufficient elements to address basic TEEP claims,
expected new standard claims (for example from
https://www.ietf.org/id/draft-mandyam-eat-01.txt), and proprietary
claim sets.

7.4. TEEP Attestation Flow

Attestations are required in TEEP under the following flows:

- When a TEE responds with device state information (dsi) to the TAM
  or SP, including a "GetDeviceState" response, "InstallTA"
  response, etc.

- When a new key pair is generated for a TA-to-TAM or TA-to-SP
  communication, the keypair must be covered by an attestation,
  including "CreateSecurityDomain" response, "UpdateSecurityDomain"
  response, etc.

7.5. Attestation Key Example

The attestation hierarchy and seed required for TAM protocol
operation must be built into the device at manufacture. Additional
TEEs can be added post-manufacture using the scheme proposed, but it
is outside of the current scope of this document to detail that.

It should be noted that the attestation scheme described is based on
signatures. The only decryption that may take place is through the
use of a bootloader key.

A boot module generated attestation can be optional where the
starting point of device attestation can be at TEE certificates. A
TAM can define its policies on what kinds of TEE it trusts if TFW
attestation is not included during the TEE attestation.

7.5.1. Attestation Hierarchy Establishment: Manufacture

During manufacture the following steps are required:

1. A device-specific TFW key pair and certificate are burnt into the
device. This key pair will be used for signing operations
performed by the boot module.

2. TEE images are loaded and include a TEE instance-specific key
pair and certificate. The key pair and certificate are included
in the image and covered by the code signing hash.
3. The process for TEE images is repeated for any subordinate TEEs, which are additional TEEs after the root TEE that some devices have.

7.5.2. Attestation Hierarchy Establishment: Device Boot

During device boot the following steps are required:

1. The boot module releases the TFW private key by decrypting it with the bootloader key.

2. The boot module verifies the code-signing signature of the active TEE and places its TEE public key into a signing buffer, along with its identifier for later access. For a TEE non-compliant to this architecture, the boot module leaves the TEE public key field blank.

3. The boot module signs the signing buffer with the TFW private key.

4. Each active TEE performs the same operation as the boot module, building up their own signed buffer containing subordinate TEE information.

7.5.3. Attestation Hierarchy Establishment: TAM

Before a TAM can begin operation in the marketplace, it must obtain a TAM certificate from a CA that is registered in the trust store of devices. In this way, the TEE can check the intermediate and root CA and verify that it trusts this TAM to perform operations on the TEE.

8. Algorithm and Attestation Agility

RFC 7696 [RFC7696] outlines the requirements to migrate from one mandatory-to-implement algorithm suite to another over time. This feature is also known as crypto agility. Protocol evolution is greatly simplified when crypto agility is already considered during the design of the protocol. In the case of the Open Trust Protocol (OTrP) the diverse range of use cases, from trusted app updates for smart phones and tablets to updates of code on higher-end IoT devices, creates the need for different mandatory-to-implement algorithms already from the start.

Crypto agility in the OTrP concerns the use of symmetric as well as asymmetric algorithms. Symmetric algorithms are used for encryption of content whereas the asymmetric algorithms are mostly used for signing messages.
In addition to the use of cryptographic algorithms in OTrP there is also the need to make use of different attestation technologies. A Device must provide techniques to inform a TAM about the attestation technology it supports. For many deployment cases it is more likely for the TAM to support one or more attestation techniques whereas the Device may only support one.

9. Security Considerations

9.1. TA Trust Check at TEE

A TA binary is signed by a TA signer certificate. This TA signing certificate/private key belongs to the SP, and may be self-signed (i.e., it need not participate in a trust hierarchy). It is the responsibility of the TAM to only allow verified TAs from trusted SPs into the system. Delivery of that TA to the TEE is then the responsibility of the TEE, using the security mechanisms provided by the protocol.

We allow a way for an (untrusted) application to check the trustworthiness of a TA. An agent has a function to allow an application to query the information about a TA.

An application in the Rich O/S may perform verification of the TA by verifying the signature of the TA. The GetTAInformation function is available to return the TEE supplied TA signer and TAM signer information to the application. An application can do additional trust checks on the certificate returned for this TA. It might trust the TAM, or require additional SP signer trust chaining.

9.2. One TA Multiple SP Case

A TA for multiple SPs must have a different identifier per SP. A TA will be installed in a different SD for each respective SP.

9.3. Agent Trust Model

An agent could be malware in the vulnerable REE. A Client Application will connect its TAM provider for required TA installation. It gets command messages from the TAM, and passes the message to the agent.

The architecture enables the TAM to communicate with the device’s TEE to manage SDs and TAs. All TAM messages are signed and sensitive data is encrypted such that the agent cannot modify or capture sensitive data.
9.4. Data Protection at TAM and TEE

The TEE implementation provides protection of data on the device. It is the responsibility of the TAM to protect data on its servers.

9.5. Compromised CA

A root CA for TAM certificates might get compromised. Some TEE trust anchor update mechanism is expected from device OEMs. A compromised intermediate CA is covered by OCSP stapling and OCSP validation check in the protocol. A TEE should validate certificate revocation about a TAM certificate chain.

If the root CA of some TEE device certificates is compromised, these devices might be rejected by a TAM, which is a decision of the TAM implementation and policy choice. Any intermediate CA for TEE device certificates SHOULD be validated by TAM with a Certificate Revocation List (CRL) or Online Certificate Status Protocol (OCSP) method.

9.6. Compromised TAM

The TEE SHOULD use validation of the supplied TAM certificates and OCSP stapled data to validate that the TAM is trustworthy.

Since PKI is used, the integrity of the clock within the TEE determines the ability of the TEE to reject an expired TAM certificate, or revoked TAM certificate. Since OCSP stapling includes signature generation time, certificate validity dates are compared to the current time.

9.7. Certificate Renewal

TFW and TEE device certificates are expected to be long lived, longer than the lifetime of a device. A TAM certificate usually has a moderate lifetime of 2 to 5 years. A TAM should get renewed or rekeyed certificates. The root CA certificates for a TAM, which are embedded into the Trust Anchor store in a device, should have long lifetimes that don’t require device Trust Anchor update. On the other hand, it is imperative that OEMs or device providers plan for support of Trust Anchor update in their shipped devices.

10. IANA Considerations

This document does not require actions by IANA.
11. Acknowledgements

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12. References

12.1. Normative References


12.2. Informative References


Appendix A. History

RFC EDITOR: PLEASE REMOVE THIS SECTION

IETF Drafts

draft-00: - Initial working group document

Authors’ Addresses

Mingliang Pei
Symantec

EMail: mingliang_pei@symantec.com

Hannes Tschofenig
Arm Limited

EMail: hannes.tschofenig@arm.com

David Wheeler
Intel

EMail: david.m.wheeler@intel.com

Andrew Atyeo
Intercede

EMail: andrew.atyeo@intercede.com

Liu Dapeng
Alibaba Group

EMail: maxpassion@gmail.com
Abstract

A Trusted Execution Environment (TEE) is designed to provide a hardware-isolation mechanism to separate a regular operating system from security-sensitive application components.

This architecture document motivates the design and standardization of a protocol for managing the lifecycle of trusted applications running inside a TEE.

Status of This Memo

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1. Introduction

Applications executing in a device are exposed to many different attacks intended to compromise the execution of the application, or reveal the data upon which those applications are operating. These attacks increase with the number of other applications on the device, with such other applications coming from potentially untrustworthy sources. The potential for attacks further increase with the complexity of features and applications on devices, and the unintended interactions among those features and applications. The danger of attacks on a system increases as the sensitivity of the applications or data on the device increases. As an example, exposure of emails from a mail client is likely to be of concern to its owner, but a compromise of a banking application raises even greater concerns.
The Trusted Execution Environment (TEE) concept is designed to execute applications in a protected environment that separates applications inside the TEE from the regular operating system and from other applications on the device. This separation reduces the possibility of a successful attack on application components and the data contained inside the TEE. Typically, application components are chosen to execute inside a TEE because those application components perform security sensitive operations or operate on sensitive data. An application component running inside a TEE is referred to as a Trusted Application (TA), while a normal application running in the regular operating system is referred to as an Untrusted Application (UA).

The TEE uses hardware to enforce protections on the TA and its data, but also presents a more limited set of services to applications inside the TEE than is normally available to UA’s running in the normal operating system.

But not all TEEs are the same, and different vendors may have different implementations of TEEs with different security properties, different features, and different control mechanisms to operate on TAs. Some vendors may themselves market multiple different TEEs with different properties attuned to different markets. A device vendor may integrate one or more TEEs into their devices depending on market needs.

To simplify the life of developers and service providers interacting with TAs in a TEE, an interoperable protocol for managing TAs running in different TEEs of various devices is needed. In this TEE ecosystem, there often arises a need for an external trusted party to verify the identity, claims, and rights of Service Providers (SP), devices, and their TEEs. This trusted third party is the Trusted Application Manager (TAM).

This protocol addresses the following problems:

- A Service Provider (SP) intending to provide services through a TA to users of a device needs to determine security-relevant information of a device before provisioning their TA to the TEE within the device. Examples include the verification of the device ‘root of trust’ and the type of TEE included in a device.

- A TEE in a device needs to determine whether a Service Provider (SP) that wants to manage a TA in the device is authorized to manage TAs in the TEE, and what TAs the SP is permitted to manage.
- The parties involved in the protocol must be able to attest that a TEE is genuine and capable of providing the security protections required by a particular TA.

- A Service Provider (SP) must be able to determine if a TA exists (is installed) on a device (in the TEE), and if not, install the TA in the TEE.

- A Service Provider (SP) must be able to check whether a TA in a device’s TEE is the most up-to-date version, and if not, update the TA in the TEE.

- A Service Provider (SP) must be able to remove a TA in a device’s TEE if the SP is no longer offering such services or the services are being revoked from a particular user (or device). For example, if a subscription or contract for a particular service has expired, or a payment by the user has not been completed or has been rescinded.

- A Service Provider (SP) must be able to define the relationship between cooperating TAs under the SP’s control, and specify whether the TAs can communicate, share data, and/or share key material.

2. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

The following terms are used:

- Client Application: An application running in a Rich Execution Environment, such as an Android, Windows, or iOS application. We sometimes refer to this as the 'Client App'.

- Device: A physical piece of hardware that hosts a TEE along with a Rich Execution Environment. A Device contains a default list of Trust Anchors that identify entities (e.g., TAMs) that are trusted by the Device. This list is normally set by the Device Manufacturer, and may be governed by the Device’s network carrier. The list of Trust Anchors is normally modifiable by the Device’s owner or Device Administrator. However the Device manufacturer and network carrier may restrict some modifications, for example, by not allowing the manufacturer or carrier’s Trust Anchor to be removed or disabled.
- Rich Execution Environment (REE): An environment that is provided and governed by a typical OS (e.g., Linux, Windows, Android, iOS), potentially in conjunction with other supporting operating systems and hypervisors; it is outside of the TEE. This environment and applications running on it are considered un-trusted.

- Service Provider (SP): An entity that wishes to provide a service on Devices that requires the use of one or more Trusted Applications. A Service Provider requires the help of a TAM in order to provision the Trusted Applications to remote devices.

- Device User: A human being that uses a device. Many devices have a single device user. Some devices have a primary device user with other human beings as secondary device users (e.g., parent allowing children to use their tablet or laptop). Relates to Device Owner and Device Administrator.

- Device Owner: A device is always owned by someone. It is common for the (primary) device user to also own the device, making the device user/owner also the device administrator. In enterprise environments it is more common for the enterprise to own the device, and device users have no or limited administration rights. In this case, the enterprise appoints a device administrator that is not the device owner.

- Device Administrator (DA): An entity that is responsible for administration of a Device, which could be the device owner. A Device Administrator has privileges on the Device to install and remove applications and TAs, approve or reject Trust Anchors, and approve or reject Service Providers, among possibly other privileges on the Device. A Device Administrator can manage the list of allowed TAMS by modifying the list of Trust Anchors on the Device. Although a Device Administrator may have privileges and Device-specific controls to locally administer a device, the Device Administrator may choose to remotely administrate a device through a TAM.

- Trust Anchor: A public key in a device whose corresponding private key is held by an entity implicitly trusted by the device. The Trust Anchor may be a certificate or it may be a raw public key along with additional data if necessary such as its public key algorithm and parameters. The Trust Anchor is normally stored in a location that resists unauthorized modification, insertion, or replacement. The digital fingerprint of a Trust Anchor may be stored along with the Trust Anchor certificate or public key. A device can use the fingerprint to uniquely identify a Trust Anchor. The Trust Anchor private key owner can sign certificates of other public keys, which conveys trust about those keys to the
device. A certificate signed by the Trust Anchor communicates that the private key holder of the signed certificate is trusted by the Trust Anchor holder, and can therefore be trusted by the device. Trust Anchors in a device may be updated by an authorized party when a Trust Anchor should be deprecated or a new Trust Anchor should be added.

- Trusted Application (TA): An application component that runs in a TEE.
- Trusted Execution Environment (TEE): An execution environment that runs alongside of, but is isolated from, an REE. A TEE has security capabilities and meets certain security-related requirements. It protects TEE assets from general software attacks, defines rigid safeguards as to data and functions that a program can access, and resists a set of defined threats. It should have at least the following three properties:
  
  (a) A device unique credential that cannot be cloned;
  
  (b) Assurance that only authorized code can run in the TEE;
  
  (c) Memory that cannot be read by code outside the TEE.

There are multiple technologies that can be used to implement a TEE, and the level of security achieved varies accordingly.

- Root-of-Trust (RoT): A hardware or software component in a device that is inherently trusted to perform a certain security-critical function. A RoT should be secure by design, small, and protected by hardware against modification or interference. Examples of RoTs include software/firmware measurement and verification using a Trust Anchor (RoT for Verification), provide signed assertions using a protected attestation key (RoT for Reporting), or protect the storage and/or use of cryptographic keys (RoT for Storage). Other RoTs are possible, including RoT for Integrity, and RoT for Measurement. Reference: NIST SP800-164 (Draft).

- Trusted Firmware (TFW): A firmware in a device that can be verified with a Trust Anchor by RoT for Verification.

- Bootloader key: This symmetric key is protected by electronic fuse (eFUSE) technology. In this context it is used to decrypt a TFW private key, which belongs to a device-unique private/public key pair. Not every device is equipped with a bootloader key.

This document uses the following abbreviations:
3. Assumptions

This specification assumes that an applicable device is equipped with one or more TEEs and each TEE is pre-provisioned with a device-unique public/private key pair, which is securely stored.

A TEE uses an isolation mechanism between Trusted Applications to ensure that one TA cannot read, modify or delete the data and code of another TA.

4. Use Cases

4.1. Payment

A payment application in a mobile device requires high security and trust about the hosting device. Payments initiated from a mobile device can use a Trusted Application to provide strong identification and proof of transaction.

For a mobile payment application, some biometric identification information could also be stored in a TEE. The mobile payment application can use such information for authentication.

A secure user interface (UI) may be used in a mobile device to prevent malicious software from stealing sensitive user input data. Such an application implementation often relies on a TEE for user input protection.
4.2. Authentication

For better security of authentication, a device may store its sensitive authentication keys inside a TEE, providing hardware-protected security key strength and trusted code execution.

4.3. Internet of Things

The Internet of Things (IoT) has been posing threats to networks and national infrastructures because of existing weak security in devices. It is very desirable that IoT devices can prevent malware from manipulating actuators (e.g., unlocking a door), or stealing or modifying sensitive data such as authentication credentials in the device. A TEE can be the best way to implement such IoT security functions.

TEEs could be used to store variety of sensitive data for IoT devices. For example, a TEE could be used in smart door locks to store a user’s biometric information for identification, and for protecting access the locking mechanism.

4.4. Confidential Cloud Computing

A tenant can store sensitive data in a TEE in a cloud computing server such that only the tenant can access the data, preventing the cloud hosting provider from accessing the data. A tenant can run TAs inside a server TEE for secure operation and enhanced data security. This provides benefits not only to tenants with better data security but also to cloud hosting provider for reduced liability and increased cloud adoption.

5. Architecture

5.1. System Components

The following are the main components in the system. Full descriptions of components not previously defined are provided below. Interactions of all components are further explained in the following paragraphs.
Service Providers (SP) and Device Administrators (DA) utilize the services of a TAM to manage TAs on Devices. SPs do not directly interact with devices. DAs may elect to use a TAM for remote administration of TAs instead of managing each device directly.

TAM: A TAM is responsible for performing lifecycle management activity on TA’s on behalf of Service Providers and Device Administrators. This includes creation and deletion of TA’s, and may include, for example, over-the-air updates to keep an SP’s TAs up-to-date and clean up when a version should be removed. TAMs may provide services that make it easier for SPs or DAs to use the TAM’s service to manage multiple devices, although that is not required of a TAM.

The TAM performs its management of TA’s through an interaction with a Device’s TEEP Broker. As shown in Figure 1, the TAM cannot directly contact a Device, but must wait for a TEEP Broker or a Client Application to contact the TAM requesting a particular service. This architecture is intentional in order to accommodate network and application firewalls that normally protect user and enterprise devices from arbitrary connections from external network entities.

A TAM may be publicly available for use by many SPs, or a TAM may be private, and accessible by only one or a limited number of SPs.

Figure 1: Notional Architecture of TEEP
It is expected that manufacturers and carriers will run their own private TAM. Another example of a private TAM is a TAM running as a Software-as-a-Service (SaaS) within an SP.

A SP or Device Administrator chooses a particular TAM based on whether the TAM is trusted by a Device or set of Devices. The TAM is trusted by a device if the TAM’s public key is an authorized Trust Anchor in the Device. A SP or Device Administrator may run their own TAM, however the Devices they wish to manage must include this TAM’s public key in the Trust Anchor list.

A SP or Device Administrator is free to utilize multiple TAMs. This may be required for a SP to manage multiple different types of devices from different manufacturers, or devices on different carriers, since the Trust Anchor list on these different devices may contain different TAMs. A Device Administrator may be able to add their own TAM’s public key or certificate to the Trust Anchor list on all their devices, overcoming this limitation.

Any entity is free to operate a TAM. For a TAM to be successful, it must have its public key or certificate installed in Devices Trust Anchor list. A TAM may set up a relationship with device manufacturers or carriers to have them install the TAM’s keys in their device’s Trust Anchor list. Alternatively, a TAM may publish its certificate and allow Device Administrators to install the TAM’s certificate in their devices as an after-market-action.

- TEEP Broker: The TEEP Broker is an application running in a Rich Execution Environment (REE) that enables the message protocol exchange between a TAM and a TEE in a device. The TEEP Broker does not process messages on behalf of a TEE, but merely is responsible for relaying messages from the TAM to the TEE, and for returning the TEE’s responses to the TAM.

A Client Application is expected to communicate with a TAM to request TAs that it needs to use. The Client Application needs to pass the messages from the TAM to TEEs in the device. This calls for a component in the REE that Client Applications can use to pass messages to TEEs. The TEEP Broker is thus an application in the REE or software library that can relay messages from a Client Application to a TEE in the device. A device usually comes with only one active TEE. A TEE may provide such a Broker to the device manufacturer to be bundled in devices. Such a TEE must also include a Broker counterpart, namely, a TEEP Agent inside the TEE, to parse TAM messages sent through the Broker. A TEEP Broker is generally acting as a dummy relaying box with just the TEE interacting capability; it doesn’t need and shouldn’t parse protocol messages.
- TEEP Agent: the TEEP Agent is a processing module running inside a TEE that receives TAM requests that are relayed via a TEEP Broker that runs in an REE. A TEEP Agent in the TEE may parse requests or forward requests to other processing modules in a TEE, which is up to a TEE provider’s implementation. A response message corresponding to a TAM request is sent by a TEEP Agent back to a TEEP Broker.

- Certification Authority (CA): Certificate-based credentials used for authenticating a device, a TAM and an SP. A device embeds a list of root certificates (Trust Anchors), from trusted CAs that a TAM will be validated against. A TAM will remotely attest a device by checking whether a device comes with a certificate from a CA that the TAM trusts. The CAs do not need to be the same; different CAs can be chosen by each TAM, and different device CAs can be used by different device manufacturers.

5.2. Different Renditions of TEEP Architecture

There is nothing prohibiting a device from implementing multiple TEEs. In addition, some TEEs (for example, SGX) present themselves as separate containers within memory without a controlling manager within the TEE. In these cases, the rich operating system hosts multiple TEEP brokers, where each broker manages a particular TEE or set of TEEs. Enumeration and access to the appropriate broker is up to the rich OS and the applications. Verification that the correct TA has been reached then becomes a matter of properly verifying TA attestations, which are unforgeable. The multiple TEE approach is shown in the diagram below. For brevity, TEEP Broker 2 is shown interacting with only one TAM and UA, but no such limitation is intended to be implied in the architecture.
Figure 2: Notional Architecture of TEEP with multiple TEEs

In the diagram above, TEEP Broker 1 controls interactions with the TA’s in TEE-1, and TEEP Broker 2 controls interactions with the TA’s in TEE-2. This presents some challenges for a TAM in completely managing the device, since a TAM may not interact with all the TEEP Brokers on a particular platform. In addition, since TEE’s may be physically separated, with wholly different resources, there may be no need for TEEP Brokers to share information on installed TAs or
resource usage. However, the architecture guarantees that the TAM will receive all the relevant information from the TEEP Broker to which it communicates.

5.3. Multiple TAMs and Relationship to TAs

As shown in Figure 2, the TEEP Broker provides connections from the TEE and the Client App to one or more TAMs. The selection of which TAM to communicate with is dependent on information from the Client App and is directly related to the TA.

When a SP offers a service which requires a TA, the SP associates that service with a specific TA. The TA itself is digitally signed, protecting its integrity, but the signature also links the TA back to the signer. The signer is usually the SP, but in some cases may be another party that the SP trusts. The SP selects one or more TAMs through which to offer their service, and communicates the information of the service and the specific client apps and TAs to the TAM.

The SP chooses TAMs based upon the markets into which the TAM can provide access. There may be TAMs that provide services to specific types of mobile devices, or mobile device operating systems, or specific geographical regions or network carriers. A SP may be motivated to utilize multiple TAMs for its service in order to maximize market penetration and availability on multiple types of devices. This likely means that the same service will be available through multiple TAMs.

When the SP publishes the Client App to an app store or other app repositories, the SP binds the Client App with a manifest that identifies what TAMs can be contacted for the TA. In some situations, an SP may use only a single TAM - this is likely the case for enterprise applications or SPs serving a closed community. For broad public apps, there will likely be multiple TAMs in the manifest - one servicing one brand of mobile device and another servicing a different manufacturer, etc. Because different devices and different manufacturers trust different TAMs, the manifest will include different TAMs that support this SP’s client app and TA. Multiple TAMs allow the SP to provide their service and this app (and TA) to multiple different devices.

When the TEEP Broker receives a request to contact the TAM for a Client App in order to install a TA, a list of TAMs may be provided. The TEEP Broker selects a single TAM that is consistent with the list of trusted TAMs (trust anchors) provisioned on the device. For any client app, there should be only a single TAM for the TEEP Broker to contact. This is also the case when a Client App uses multiple TAs,
or when one TA depends on another TA in a software dependency (see section TBD). The reason is that the SP should provide each TAM that it places in the Client App’s manifest all the TAs that the app requires. There is no benefit to going to multiple different TAMS, and there is no need for a special TAM to be contacted for a specific TA.

[Note: This should always be the case. When a particular device or TEE supports only a special proprietary attestation mechanism, then a specific TAM will be needed that supports that attestation scheme. The TAM should also support standard attestation signatures as well. It is highly unlikely that a set of TAs would use different proprietary attestation mechanisms since a TEE is likely to support only one such proprietary scheme.]

[Note: This situation gets more complex in situations where a Client App expects another application or a device to already have a specific TA installed. This situation does not occur with SGX, but could occur in situations where the secure world maintains an trusted operating system and runs an entire trusted system with multiple TAs running. This requires more discussion.]

5.4. Client Apps, Trusted Apps, and Personalization Data

In TEEP, there is an explicit relationship and dependence between the client app in the REE and one or more TAs in the TEE, as shown in Figure 2. From the perspective of a device user, a client app that uses one or more TA’s in a TEE appears no different from any other untrusted application in the REE. However, the way the client app and its corresponding TA’s are packaged, delivered, and installed on the device can vary. The variations depend on whether the client app and TA are bundled together or are provided separately, and this has implications to the management of the TAs in the TEE. In addition to the client app and TA, the TA and/or TEE may require some additional data to personalize the TA to the service provider or the device user. This personalization data is dependent on the TEE, the TA and the SP; an example of personalization data might be username and password of the device user's account with the SP, or a secret symmetric key used to by the TA to communicate with the SP. The personalization data must be encrypted to preserve the confidentiality of potentially sensitive data contained within it. Other than this requirement to support confidentiality, TEEP place no limitations or requirements on the personalization data.

There are three possible cases for bundling of the Client App, TA, and personalization data:
1. The Client App, TA, and personalization data are all bundled together in a single package by the SP and provided to the TEEP Broker through the TAM.

2. The Client App and the TA are bundled together in a single binary, which the TAM or a publicly accessible app store maintains in repository, and the personalization data is separately provided by the SP. In this case, the personalization data is collected by the TAM and included in the InstallTA message to the TEEP Broker.

3. All components are independent. The device user installs the Client App through some independent or device-specific mechanism, and the TAM provides the TA and personalization data from the SP. Delivery of the TA and personalization data may be combined or separate.

5.5. Examples of Application Delivery Mechanisms in Existing TEEs

In order to better understand these cases, it is helpful to review actual implementations of TEEs and their application delivery mechanisms.

In Intel Software Guard Extensions (SGX), the Client App and TA are typically bound into the same binary (Case 2). The TA is compiled into the Client App binary using SGX tools, and exists in the binary as a shared library (\*.so or \*.dll). The Client App loads the TA into an SGX enclave when the client needs the TA. This organization makes it easy to maintain compatibility between the Client App and the TA, since they are updated together. It is entirely possible to create a Client App that loads an external TA into an SGX enclave and use that TA (Case 3). In this case, the Client App would require a reference to an external file or download such a file dynamically, place the contents of the file into memory, and load that as a TA. Obviously, such file or downloaded content must be properly formatted and signed for it to be accepted by the SGX TEE. In SGX, for Case 2 and Case 3, the personalization data is normally loaded into the SGX enclave (the TA) after the TA has started. Although Case 1 is possible with SGX, there are no instances of this known to be in use at this time, since such a construction would require a special installation program and SGX TA to receive the encrypted binary, decrypt it, separate it into the three different elements, and then install all three. This installation is complex, because the Client App decrypted inside the TEE must be passed out of the TEE to an installer in the REE which would install the Client App; this assumes that the Client App binary includes the TA code also, otherwise there is a significant problem in getting the SGX enclave code (the TA) from the TEE, through the installer and into the Client App in a trusted fashion. Finally, the
personalization data would need to be sent out of the TEE (encrypted in an SGX enclave-to-enclave manner) to the REE’s installation app, which would pass this data to the installed Client App, which would in turn send this data to the SGX enclave (TA). This complexity is due to the fact that each SGX enclave is separate and does not have direct communication to one another.

[NOTE: Need to add an equivalent discussion for an ARM/TZ implementation]

5.6. TEEP Architectural Support for Client App, TA, and Personalization Data Delivery

This section defines TEEP support for the three different cases for delivery of the Client App, TA, and personalization data.

[Note: discussion of format of this single binary, and who/what is responsible for splitting these things apart, and installing the client app into the REE, the TA into the TEE, and the personalization data into the TEE or TA. Obviously the decryption must be done by the TEE but this may not be supported by all TAs.]

5.7. Entity Relations

This architecture leverages asymmetric cryptography to authenticate a device to a TAM. Additionally, a TEE in a device authenticates a TAM and TA signer. The provisioning of Trust Anchors to a device may different from one use case to the other. A device administrator may want to have the capability to control what TAs are allowed. A device manufacturer enables verification of the TA signers and TAM providers; it may embed a list of default Trust Anchors that the signer of an allowed TA’s signer certificate should chain to. A device administrator may choose to accept a subset of the allowed TAs via consent or action of downloading.
Figure 3: Entities

(App Developer) (App Store) (TAM) (Device with TEE) (CAs)

1. Build two apps:
   - Client App
   - TA

   Client App -- 2a. --> | ----- 3. Install -------> |
   TA ------- 2b. Supply -------> | 4. Messaging-->

Figure 4 shows an application developer building two applications: 1) a rich Client Application; 2) a TA that provides some security functions to be run inside a TEE. At step 2, the application developer uploads the Client Application (2a) to an Application Store. The Client Application may optionally bundle the TA binary. Meanwhile, the application developer may provide its TA to a TAM provider that will be managing the TA in various devices. 3. A user will go to an Application Store to download the Client Application. The Client Application will trigger TA installation by initiating communication with a TAM. This is the step 4. The Client Application will get messages from TAM, and interacts with device TEE via an Agent.

The following diagram shows a system diagram about the entity relationships between CAs, TAMs, SPs and devices.
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<td>List of Trusted FW/TEE CAs</td>
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<td>TAM Key/Cert</td>
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<td>FW Key/Cert</td>
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### Figure 5: Keys

In the previous diagram, different CAs can be used for different types of certificates. Messages are always signed, where the signer key is the message originator’s private key such as that of a TAM, the private key of trusted firmware (TFW), or a TEE’s private key.

The main components consist of a set of standard messages created by a TAM to deliver TA management commands to a device, and device attestation and response messages created by a TEE that responds to a TAM’s message.

It should be noted that network communication capability is generally not available in TAs in today’s TEE-powered devices. The networking functionality must be delegated to a rich Client Application. Client Applications will need to rely on an agent in the REE to interact with a TEE for message exchanges. Consequently, a TAM generally communicates with a Client Application about how it gets messages that originate from a TEE inside a device. Similarly, a TA or TEE generally gets messages from a TAM via some Client Application,
namely, a TEEP Broker in this protocol architecture, not directly from the network.

It is imperative to have an interoperable protocol to communicate with different TAMs and different TEEs in different devices. This is the role of the Broker, which is a software component that bridges communication between a TAM and a TEE. Furthermore the Broker communicates with a Agent inside a TEE that is responsible to process TAM requests. The Broker in REE does not need to know the actual content of messages except for the TEE routing information.

5.8. Trust Anchors in TEE

Each TEE comes with a trust store that contains a whitelist of Trust Anchors that are used to validate a TAM’s certificate. A TEE will accept a TAM to create new Security Domains and install new TAs on behalf of an SP only if the TAM’s certificate is chained to one of the root CA certificates in the TEE’s trust store.

A TEE’s trust store is typically preloaded at manufacturing time. It is out of the scope in this document to specify how the trust anchors should be updated when a new root certificate should be added or existing one should be updated or removed. A device manufacturer is expected to provide its TEE trust anchors live update or out-of-band update to Device Administrators.

When trust anchor update is carried out, it is imperative that any update must maintain integrity where only authentic trust anchor list from a device manufacturer or a Device Administrator is accepted. This calls for a complete lifecycle flow in authorizing who can make trust anchor update and whether a given trust anchor list are non-tampered from the original provider. The signing of a trust anchor list for integrity check and update authorization methods are desirable to be developed. This can be addressed outside of this architecture document.

Before a TAM can begin operation in the marketplace to support a device with a particular TEE, it must obtain a TAM certificate from a CA that is listed in the trust store of the TEE.

5.9. Trust Anchors in TAM

The Trust Anchor store in a TAM consists of a list of CA certificates that sign various device TEE certificates. A TAM will accept a device for TA management if the TEE in the device uses a TEE certificate that is chained to a CA that the TAM trusts.
5.10. Keys and Certificate Types

This architecture leverages the following credentials, which allow delivering end-to-end security without relying on any transport security.

<table>
<thead>
<tr>
<th>Key Entity Name</th>
<th>Location</th>
<th>Issuer</th>
<th>Checked Against</th>
<th>Cardinality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. TFW key pair and certificate</td>
<td>Device secure storage</td>
<td>FW CA</td>
<td>A whitelist of FW root CA trusted by TAMs</td>
<td>1 per device</td>
</tr>
<tr>
<td>2. TEE key pair and certificate</td>
<td>Device TEE</td>
<td>TEE CA under a root CA</td>
<td>A whitelist of TEE root CA trusted by TAMs</td>
<td>1 per device</td>
</tr>
<tr>
<td>3. TAM key pair and certificate</td>
<td>TAM provider</td>
<td>TAM CA under a root CA</td>
<td>A whitelist of TAM root CA embedded in TEE</td>
<td>1 or multiple can be used by a TAM</td>
</tr>
<tr>
<td>4. SP key pair and certificate</td>
<td>SP</td>
<td>SP signer CA</td>
<td>A SP uses a TAM. TA is signed by a SP signer. TEE delegates trust of TA to TAM. SP signer is associated with a TA as the owner.</td>
<td>1 or multiple can be used by a TAM</td>
</tr>
</tbody>
</table>

Figure 6: Key and Certificate Types

1. TFW key pair and certificate: A key pair and certificate for evidence of trustworthy firmware in a device. This key pair is optional for TEEP architecture. Some TEE may present its trusted attributes to a TAM using signed attestation with a TFW key. For example, a platform that uses a hardware based TEE can have attestation data signed by a hardware protected TFW key.

   - Location: Device secure storage
   - Supported Key Type: RSA and ECC
   - Issuer: OEM CA
2. TEE key pair and certificate: It is used for device attestation to a remote TAM and SP.

- This key pair is burned into the device by the device manufacturer. The key pair and its certificate are valid for the expected lifetime of the device.
- Location: Device TEE
- Supported Key Type: RSA and ECC
- Issuer: A CA that chains to a TEE root CA
- Checked Against: A whitelist of TEE root CAs trusted by TAMS
- Cardinality: One per device

3. TAM key pair and certificate: A TAM provider acquires a certificate from a CA that a TEE trusts.

- Location: TAM provider
- Supported Key Type: RSA and ECC.
- Supported Key Size: RSA 2048-bit, ECC P-256 and P-384. Other sizes should be anticipated in future.
- Issuer: TAM CA that chains to a root CA
- Checked Against: A whitelist of TAM root CAs embedded in a TEE
- Cardinality: One or multiple can be used by a TAM

4. SP key pair and certificate: An SP uses its own key pair and certificate to sign a TA.

- Location: SP
- Supported Key Type: RSA and ECC
- Supported Key Size: RSA 2048-bit, ECC P-256 and P-384. Other sizes should be anticipated in future.
- Issuer: An SP signer CA that chains to a root CA
5.11. Scalability

This architecture uses a PKI. Trust Anchors exist on the devices to enable the TEE to authenticate TAMs, and TAMs use Trust Anchors to authenticate TEEs. Since a PKI is used, many intermediate CA certificates can chain to a root certificate, each of which can issue many certificates. This makes the protocol highly scalable. New factories that produce TEEs can join the ecosystem. In this case, such a factory can get an intermediate CA certificate from one of the existing roots without requiring that TAMs are updated with information about the new device factory. Likewise, new TAMs can join the ecosystem, providing they are issued a TAM certificate that chains to an existing root whereby existing TEEs will be allowed to be personalized by the TAM without requiring changes to the TEE itself. This enables the ecosystem to scale, and avoids the need for centralized databases of all TEEs produced or all TAMs that exist.

5.12. Message Security

Messages created by a TAM are used to deliver TA management commands to a device, and device attestation and messages created by the device TEE to respond to TAM messages.

These messages are signed end-to-end and are typically encrypted such that only the targeted device TEE or TAM is able to decrypt and view the actual content.

5.13. Security Domain

No security domain (SD) is explicitly assumed in a TEE for TA management. Some TEE, for example, some TEE compliant with Global Platform (GP), may continue to choose to use SD to organize resource partition and security boundaries. It is up to a TEE implementation to decide how a SD is attached to a TA installation, for example, one SD could be created per TA.


Step 1: Prepare Images for Devices

1. [TEE vendor] Deliver TEE Image (CODE Binary) to device OEM
2. [CA] Deliver root CA Whitelist

3. [Soc] Deliver TFW Image

Step 2: Inject Key Pairs and Images to Devices

1. [OEM] Generate TFW Key Pair (May be shared among multiple devices)

2. [OEM] Flash signed TFW Image and signed TEE Image onto devices (signed by TFW Key)

Step 3: Set up attestation key pairs in devices

1. [OEM] Flash TFW Public Key and a bootloader key.

2. [TFW/TEE] Generate a unique attestation key pair and get a certificate for the device.

Step 4: Set up Trust Anchors in devices

1. [TFW/TEE] Store the key and certificate encrypted with the bootloader key

2. [TEE vendor or OEM] Store trusted CA certificate list into devices

6. TEEP Broker

A TEE and TAs do not generally have the capability to communicate to the outside of the hosting device. For example, GlobalPlatform [GPTEE] specifies one such architecture. This calls for a software module in the REE world to handle the network communication. Each Client Application in the REE might carry this communication functionality but such functionality must also interact with the TEE for the message exchange.

The TEE interaction will vary according to different TEEs. In order for a Client Application to transparently support different TEEs, it is imperative to have a common interface for a Client Application to invoke for exchanging messages with TEEs.

A shared module in REE comes to meet this need. A TEEP broker is an application running in the REE of the device or an SDK that facilitates communication between a TAM and a TEE. It also provides interfaces for Client Applications to query and trigger TA installation that the application needs to use.
It isn’t always that a Client Application directly calls such a Broker to interact with a TEE. A REE Application Installer might carry out TEE and TAM interaction to install all required TAs that a Client Application depends. A Client Application may have a metadata file that describes the TAs it depends on and the associated TAM that each TA installation goes to use. The REE Application Installer can inspect the application metadata file and installs TAs on behalf of the Client Application without requiring the Client Application to run first.

This interface for Client Applications or Application Installers may be commonly in a form of an OS service call for an REE OS. A Client Application or an Application Installer interacts with the device TEE and the TAMS.

6.1. Role of the TEEP Broker

A TEEP Broker abstracts the message exchanges with a TEE in a device. The input data is originated from a TAM or the first initialization call to trigger a TA installation.

The Broker doesn’t need to parse a message content received from a TAM that should be processed by a TEE. When a device has more than one TEE, one TEEP Broker per TEE could be present in REE. A TEEP Broker interacts with a TEEP Agent inside a TEE.

A TAM message may indicate the target TEE where a TA should be installed. A compliant TEEP protocol should include a target TEE identifier for a TEEP Broker when multiple TEEs are present.

The Broker relays the response messages generated from a TEEP Agent in a TEE to the TAM. The Broker is not expected to handle any network connection with an application or TAM.

The Broker only needs to return an error message if the TEE is not reachable for some reason. Other errors are represented as response messages returned from the TEE which will then be passed to the TAM.

6.2. TEEP Broker Implementation Consideration

A Provider should consider methods of distribution, scope and concurrency on devices and runtime options when implementing a TEEP Broker. Several non-exhaustive options are discussed below. Providers are encouraged to take advantage of the latest communication and platform capabilities to offer the best user experience.
6.2.1. TEEP Broker Distribution

The Broker installation is commonly carried out at OEM time. A user can dynamically download and install a Broker on-demand.

6.2.2. Number of TEEP Brokers

There should be generally only one shared TEEP Broker in a device. The device’s TEE vendor will most probably supply one Broker. When multiple TEEs are present in a device, one TEEP Broker per TEE may be used.

When only one Broker is used per device, the Broker provider is responsible to allow multiple TAMs and TEE providers to achieve interoperability. With a standard Broker interface, each TAM can implement its own SDK for its SP Client Applications to work with this Broker.

Multiple independent Broker providers can be used as long as they have standard interface to a Client Application or TAM SDK. Only one Broker is generally expected in a device.

7. Attestation

Attestation is the process through which one entity (an attester) presents a series of claims to another entity (a verifier), and provides sufficient proof that the claims are true. Different verifiers may have different standards for attestation proofs and not all attestations are acceptable to every verifier. TEEP attestations are based upon the use of an asymmetric key pair under the control of the TEE to create digital signatures across a well-defined claim set.

In TEEP, the primary purpose of an attestation is to allow a device to prove to TAMs and SPs that a TEE in the device has particular properties, was built by a particular manufacturer, or is executing a particular TA. Other claims are possible; this architecture specification does not limit the attestation claims, but defines a minimal set of claims required for TEEP to operate properly. Extensions to these claims are possible, but are not defined in the TEEP specifications. Other standards or groups may define the format and semantics of extended claims. The TEEP specification defines the claims format such that these extended claims may be easily included in a TEEP attestation message.

As of the writing of this specification, device and TEE attestations have not been standardized across the market. Different devices, manufacturers, and TEEs support different attestation algorithms and mechanisms. In order for TEEP to be inclusive, the attestation
format shall allow for both proprietary attestation signatures, as well as a standardized form of attestation signature. Either form of attestation signature may be applied to a set of TEEP claims, and both forms of attestation shall be considered conformant with TEEP. However, it should be recognized that not all TAMs or SPs may be able to process all proprietary forms of attestations. All TAMs and SPs MUST be able to process the TEEP standard attestation format and attached signature.

The attestation formats and mechanisms described and mandated by TEEP shall convey a particular set of cryptographic properties based on minimal assumptions. The cryptographic properties are conveyed by the attestation; however the assumptions are not conveyed within the attestation itself.

The assumptions which may apply to an attestation have to do with the quality of the attestation and the quality and security provided by the TEE, the device, the manufacturer, or others involved in the device or TEE ecosystem. Some of the assumptions that might apply to an attestations include (this may not be a comprehensive list):

- Assumptions regarding the security measures a manufacturer takes when provisioning keys into devices/TEEs;
- Assumptions regarding what hardware and software components have access to the Attestation keys of the TEE;
- Assumptions related to the source or local verification of claims within an attestation prior to a TEE signing a set of claims;
- Assumptions regarding the level of protection afforded to attestation keys against exfiltration, modification, and side channel attacks;
- Assumptions regarding the limitations of use applied to TEE Attestation keys;
- Assumptions regarding the processes in place to discover or detect TEE breeches; and
- Assumptions regarding the revocation and recovery process of TEE attestation keys.

TAMs and SPs must be comfortable with the assumptions that are inherently part of any attestation they accept. Alternatively, any TAM or SP may choose not to accept an attestation generated from a particular manufacturer or device’s TEE based on the inherent
assumptions. The choice and policy decisions are left up to the particular TAM/SP.

Some TAMs or SPs may require additional claims in order to properly authorize a device or TEE. These additional claims may help clear up any assumptions for which the TAM/SP wants to alleviate. The specific format for these additional claims are outside the scope of this specification, but the OTrP protocol SHALL allow these additional claims to be included in the attestation messages.

The following sub-sections define the cryptographic properties conveyed by the TEEP attestation, the basic set of TEEP claims required in a TEEP attestation, the TEEP attestation flow between the TAM the device TEE, and some implementation examples of how an attestation key may be realized in a real TEEP device.

7.1. Attestation Cryptographic Properties

The attestation constructed by TEEP must convey certain cryptographic properties from the attestor to the verifier; in the case of TEEP, the attestation must convey properties from the device to the TAM and/or SP. The properties required by TEEP include:

- Non-repudiation, Unique Proof of Source - the cryptographic digital signature across the attestation, and optionally along with information in the attestation itself SHALL uniquely identify a specific TEE in a specific device.

- Integrity of claims - the cryptographic digital signature across the attestation SHALL cover the entire attestation including all meta data and all the claims in the attestation, ensuring that the attestation has not be modified since the TEE signed the attestation.

Standard public key algorithms such as RSA and ECDSA digital signatures convey these properties. Group public key algorithms such as EPID can also convey these properties, if the attestation includes a unique device identifier and an identifier for the TEE. Other cryptographic operations used in other attestation schemes may also convey these properties.

The TEEP standard attestation format SHALL use one of the following digital signature formats:

- RSA-2048 with SHA-256 or SHA-384 in RSA-PKCS1-v1_5 or PSS format
- RSA-3072 with SHA-256 or SHA-384 in RSASSA-PKCS1-v1_5 or PSS format
- ECDSA-256 using NIST P256 curve using SHA-256
- ECDSA-384 using NIST P384 curve using SHA-384
- HashEdDSA using Ed25519 with SHA-512 (Ed25519ph in RFC8032) and context="TEEP Attestation"
- EdDSA using Ed448 with SHA256 (Ed448ph in RFC8032) and context="TEEP Attestation"

All TAMs and SPs MUST be able to accept attestations using these algorithms, contingent on their acceptance of the assumptions implied by the attestations.

7.2. TEEP Attestation Structure

For a TEEP attestation to be useful, it must contain an information set allowing the TAM and/or SP to assess the attestation and make a related security policy decision. The structure of the TEEP attestation is shown in the diagram below.

```
+------(Signed By)-----------+
   |                            |
   v----------------------------
++-----------------------------++
<table>
<thead>
<tr>
<th>Attestation Header</th>
<th>The Claims</th>
</tr>
</thead>
</table>
++-----------------------------++
|                              | The Attestation Signature(s) |
++-----------------------------++

Figure 7: Structure of TEEP Attestation
```

The Attestation Header SHALL identify the "Attestation Type" and the "Attestation Signature Type" along with an "Attestation Format Version Number." The "Attestation Type" identifies the minimal set of claims that MUST be included in the attestation; this is an
identifier for a profile that defines the claims that should be included in the attestation as part of the "Action or Operation Specific Claims." The "Attestation Signature Type" identifies the type of attestation signature that is attached. The type of attestation signature SHALL be one of the standard signatures types identified by an IANA number, a proprietary signature type identified by an IANA number, or the generic "Proprietary Signature" with an accompanying proprietary identifier. Not all TAMs may be able to process proprietary signatures.

The claims in the attestation are set of mandatory and optional claims. The claims themselves SHALL be defined in an attestation claims dictionary. See the next section on TEEP Attestation Claims. Claims are grouped in profiles under an identifier (Attestation Type), however all attestations require a minimal set of claims which includes:

- **Device Identifying Info:** TEEP attestations must uniquely identify a device to the TAM and SP. This identifier allows the TAM/SP to provide services unique to the device, such as managing installed TAs, and providing subscriptions to services, and locating device-specific keying material to communicate with or authenticate the device. Additionally, device manufacturer information must be provided to provide better universal uniqueness qualities without requiring globally unique identifiers for all devices.

- **TEE Identifying info:** The type of TEE that generated this attestation must be identified. Standard TEE types are identified by an IANA number, but also must include version identification information such as the hardware, firmware, and software version of the TEE, as applicable by the TEE type. Structure to the version number is required. TEE manufacturer information for the TEE is required in order to disambiguate the same TEE type created by different manufacturers and resolve potential assumptions around manufacturer provisioning, keying and support for the TEE.

- **Liveness Proof:** A claim that includes liveness information SHALL be included which may be a large nonce or may be a timestamp and short nonce.

- **Action Specific Claims:** Certain attestation types shall include specific claims. For example an attestation from a specific TA shall include a measurement, version and signing public key for the TA.

- **Additional Claims:** (Optional – May be empty set) A TAM or SP may require specific additional claims in order to address potential assumptions, such as the requirement that a device’s REE performed
a secure boot, or that the device is not currently in a debug or non-productions state. A TAM may require a device to provide a device health attestation that may include some claims or measurements about the REE. These claims are TAM specific.

7.3. TEEP Attestation Claims

TEEP requires a set of attestation claims that provide sufficient evidence to the TAM and/or SP that the device and its TEE meet certain minimal requirements. Because attestation formats are not yet broadly standardized across the industry, standardization work is currently ongoing, and it is expected that extensions to the attestation claims will be required as new TEEs and devices are created, the set of attestation claims required by TEEP SHALL be defined in an IANA registry. That registry SHALL be defined in the OTrP protocol with sufficient elements to address basic TEEP claims, expected new standard claims (for example from https://www.ietf.org/id/draft-mandyam-eat-01.txt), and proprietary claim sets.

7.4. TEEP Attestation Flow

Attestations are required in TEEP under the following flows:

- When a TEE responds with device state information (dsi) to the TAM or SP, including a "GetDeviceState" response, "InstallTA" response, etc.

- When a new key pair is generated for a TA-to-TAM or TA-to-SP communication, the keypair must be covered by an attestation, including "CreateSecurityDomain" response, "UpdateSecurityDomain" response, etc.

7.5. Attestation Key Example

The attestation hierarchy and seed required for TAM protocol operation must be built into the device at manufacture. Additional TEEs can be added post-manufacture using the scheme proposed, but it is outside of the current scope of this document to detail that.

It should be noted that the attestation scheme described is based on signatures. The only decryption that may take place is through the use of a bootloader key.

A boot module generated attestation can be optional where the starting point of device attestation can be at TEE certificates. A TAM can define its policies on what kinds of TEE it trusts if TFW attestation is not included during the TEE attestation.
7.5.1. Attestation Hierarchy Establishment: Manufacture

During manufacture the following steps are required:

1. A device-specific TFW key pair and certificate are burnt into the device. This key pair will be used for signing operations performed by the boot module.

2. TEE images are loaded and include a TEE instance-specific key pair and certificate. The key pair and certificate are included in the image and covered by the code signing hash.

3. The process for TEE images is repeated for any subordinate TEEs, which are additional TEEs after the root TEE that some devices have.

7.5.2. Attestation Hierarchy Establishment: Device Boot

During device boot the following steps are required:

1. The boot module releases the TFW private key by decrypting it with the bootloader key.

2. The boot module verifies the code-signing signature of the active TEE and places its TEE public key into a signing buffer, along with its identifier for later access. For a TEE non-compliant to this architecture, the boot module leaves the TEE public key field blank.

3. The boot module signs the signing buffer with the TFW private key.

4. Each active TEE performs the same operation as the boot module, building up their own signed buffer containing subordinate TEE information.

7.5.3. Attestation Hierarchy Establishment: TAM

Before a TAM can begin operation in the marketplace, it must obtain a TAM certificate from a CA that is registered in the trust store of devices. In this way, the TEE can check the intermediate and root CA and verify that it trusts this TAM to perform operations on the TEE.

8. Algorithm and Attestation Agility

RFC 7696 [RFC7696] outlines the requirements to migrate from one mandatory-to-implement algorithm suite to another over time. This feature is also known as crypto agility. Protocol evolution is
greatly simplified when crypto agility is already considered during the design of the protocol. In the case of the Open Trust Protocol (OTrP) the diverse range of use cases, from trusted app updates for smart phones and tablets to updates of code on higher-end IoT devices, creates the need for different mandatory-to-implement algorithms already from the start.

Crypto agility in the OTrP concerns the use of symmetric as well as asymmetric algorithms. Symmetric algorithms are used for encryption of content whereas the asymmetric algorithms are mostly used for signing messages.

In addition to the use of cryptographic algorithms in OTrP there is also the need to make use of different attestation technologies. A Device must provide techniques to inform a TAM about the attestation technology it supports. For many deployment cases it is more likely for the TAM to support one or more attestation techniques whereas the Device may only support one.

9. Security Considerations

9.1. TA Trust Check at TEE

A TA binary is signed by a TA signer certificate. This TA signing certificate/private key belongs to the SP, and may be self-signed (i.e., it need not participate in a trust hierarchy). It is the responsibility of the TAM to only allow verified TAs from trusted SPs into the system. Delivery of that TA to the TEE is then the responsibility of the TEE, using the security mechanisms provided by the protocol.

We allow a way for an (untrusted) application to check the trustworthiness of a TA. A TEEP Broker has a function to allow an application to query the information about a TA.

An application in the Rich O/S may perform verification of the TA by verifying the signature of the TA. The GetTAInformation function is available to return the TEE supplied TA signer and TAM signer information to the application. An application can do additional trust checks on the certificate returned for this TA. It might trust the TAM, or require additional SP signer trust chaining.

9.2. One TA Multiple SP Case

A TA for multiple SPs must have a different identifier per SP. They should appear as different TAs when they are installed in the same device.
9.3. Broker Trust Model

A TEEP Broker could be malware in the vulnerable REE. A Client Application will connect its TAM provider for required TA installation. It gets command messages from the TAM, and passes the message to the Broker.

The architecture enables the TAM to communicate with the device’s TEE to manage TAs. All TAM messages are signed and sensitive data is encrypted such that the TEEP Broker cannot modify or capture sensitive data.

9.4. Data Protection at TAM and TEE

The TEE implementation provides protection of data on the device. It is the responsibility of the TAM to protect data on its servers.

9.5. Compromised CA

A root CA for TAM certificates might get compromised. Some TEE trust anchor update mechanism is expected from device OEMs. A compromised intermediate CA is covered by OCSP stapling and OCSP validation check in the protocol. A TEE should validate certificate revocation about a TAM certificate chain.

If the root CA of some TEE device certificates is compromised, these devices might be rejected by a TAM, which is a decision of the TAM implementation and policy choice. Any intermediate CA for TEE device certificates SHOULD be validated by TAM with a Certificate Revocation List (CRL) or Online Certificate Status Protocol (OCSP) method.

9.6. Compromised TAM

The TEE SHOULD use validation of the supplied TAM certificates and OCSP stapled data to validate that the TAM is trustworthy.

Since PKI is used, the integrity of the clock within the TEE determines the ability of the TEE to reject an expired TAM certificate, or revoked TAM certificate. Since OCSP stapling includes signature generation time, certificate validity dates are compared to the current time.

9.7. Certificate Renewal

TFW and TEE device certificates are expected to be long lived, longer than the lifetime of a device. A TAM certificate usually has a moderate lifetime of 2 to 5 years. A TAM should get renewed or rekeyed certificates. The root CA certificates for a TAM, which are
embedded into the Trust Anchor store in a device, should have long lifetimes that don’t require device Trust Anchor update. On the other hand, it is imperative that OEMs or device providers plan for support of Trust Anchor update in their shipped devices.

10. IANA Considerations

This document does not require actions by IANA.

11. Acknowledgements

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12. References

12.1. Normative References


12.2. Informative References


Appendix A.  History

RFC EDITOR: PLEASE REMOVE THIS SECTION

IETF Drafts

draft-00: - Initial working group document

Authors’ Addresses

Mingliang Pei
Symantec
EMail: mingliang_pei@symantec.com

Hannes Tschofenig
Arm Limited
EMail: hannes.tschofenig@arm.com

David Wheeler
Intel
EMail: david.m.wheeler@intel.com

Andrew Atyeo
Intercede
EMail: andrew.atyeo@intercede.com

Liu Dapeng
Alibaba Group
EMail: maxpassion@gmail.com
The Open Trust Protocol (OTrP)
draft-ietf-teep-opentrustprotocol-02.txt

Abstract

This document specifies the Open Trust Protocol (OTrP), a protocol that follows the Trust Execution Environment Provisioning (TEEP) architecture and provides a message protocol that provisions and manages Trusted Applications into a device with a Trusted Execution Environment (TEE).

Status of This Memo

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A.3. Example OTrP Broker Option

Appendix B. Contributors

Authors’ Addresses

1. Introduction

The Trusted Execution Environment (TEE) concept has been designed to separate a regular operating system, also referred as a Rich Execution Environment (REE), from security-sensitive applications. In a TEE ecosystem, different device vendors may use different TEE implementations. Different application providers or device administrators may choose to use different TAM providers. There calls for an interoperable protocol for managing TAs running in different TEEs of various devices is needed.

The Trusted Execution Environment Provisioning (TEEP) architecture document [TEEPArch] has set to provide a design guidance for such an interoperable protocol. This document specifies an Open Trust Protocol (OTrP) that follows the architecture guidance.

OTrP defines a mutual trust message protocol between a TAM and a TEE and relies on IETF-defined end-to-end security mechanisms, namely JSON Web Encryption (JWE), JSON Web Signature (JWS), and JSON Web Key (JWK). Other message encoding methods may be supported.

This specification defines message payloads exchanged between devices and a TAM. The messages are designed in anticipation of the use of the most common transport methods such as HTTPS.

Each TA binary and configuration data can be from either of two sources:

1. A TAM supplies the signed and encrypted TA binary and any required configuration data

2. A Client Application supplies the TA binary
This specification considers the first case where TA binary and configuration data are encrypted by recipient’s public key that TAM has to be involved. The second case will also be addressed separately.

2. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

3. Terminology

3.1. Definitions

The definitions provided below are defined as used in this document. All the terms defined in the TEEP Architecture document [TEEPArch] will be used, which are not repeated in this document.

OTrP Broker: It is the Broker as defined in the TEEP Architecture document [TEEPArch].

3.2. Abbreviations

CA Certificate Authority
OTrP Open Trust Protocol
REE Rich Execution Environment
SD Security Domain
SP Service Provider
TA Trusted Application
TEE Trusted Execution Environment
TFW Trusted Firmware
TAM Trusted Application Manager

4. OTrP Entities and Trust Model
4.1. System Components

The same system components as defined in the TEEP Architecture document [TEEPArch] are used in OTrP, including TAM, CA, TEE, REE, and OTrP Broker (a.k.a Broker).

Secure boot (for the purposes of OTrP) is optional in enabling authenticity checking of TEEs by the TAM. A TAM provider can choose it policy whether it trusts a TEE if the underlying firmware attestation information is not included.

OTrP uses trust anchors to establish trust between TEEs and TAMs and verifies that they communicate in a trusted way when performing lifecycle management transactions.

4.2. Trust Anchors in TEE

This assumes the Trust Anchor specification defined in the TEEP Architecture document [TEEPArch].

Each TEE comes with a trust store that contains a whitelist of root CA certificates that are used to validate a TAM’s certificate. A TEE will accept a TAM to create new Security Domains and install new TAs on behalf of a SP only if the TAM’s certificate is chained to one of the root CA certificates in the TEE’s trust store.

4.3. Trust Anchors in TAM

The Trust Anchor set in a TAM consists of a list of Certificate Authority certificates that signs various device TEE certificates. A TAM decides what TEE and optionally TFW it will trust when TFW signature data is present in an attestation.

4.4. Keys and Certificate Types

OTrP leverages the following list of trust anchors and identities in generating signed and encrypted command messages that are exchanged between a device’s TEE and a TAM. With these security artifacts, OTrP Messages are able to deliver end-to-end security without relying on any transport security.
<table>
<thead>
<tr>
<th>Key Entity Name</th>
<th>Location</th>
<th>Issuer</th>
<th>Trust Implication</th>
<th>Cardinality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. TFW key pair and</td>
<td>Device secure</td>
<td>FW CA</td>
<td>A whitelist of FW root CA trusted by TAMs</td>
<td>1 per device</td>
</tr>
<tr>
<td>certificate</td>
<td>storage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. TEE key pair and</td>
<td>Device TEE</td>
<td>TEE CA</td>
<td>A whitelist of TEE root CA trusted by TAMs</td>
<td>1 per device</td>
</tr>
<tr>
<td>certificate</td>
<td>TEE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. TAM key pair and</td>
<td>TAM provider TAM</td>
<td>TAM CA</td>
<td>A whitelist of TAM root CA embedded in TEE</td>
<td>1 or multiple</td>
</tr>
<tr>
<td>certificate</td>
<td>provider</td>
<td>under a root CA</td>
<td></td>
<td>can be used by a TAM</td>
</tr>
<tr>
<td>4. SP key pair and</td>
<td>SP</td>
<td>SP signer CA</td>
<td>TAM manages SP. TA trust is delegated to TAM. TEE trusts TAM to ensure that a TA is trustworthy.</td>
<td>1 or multiple</td>
</tr>
<tr>
<td>certificate</td>
<td></td>
<td></td>
<td></td>
<td>can be used by a TAM</td>
</tr>
</tbody>
</table>

Table 1: Key and Certificate Types

1. TFW key pair and certificate: A key pair and certificate for evidence of trustworthy firmware in a device. This key pair is optional. Some TEE may present its trusted attributes to a TAM using signed attestation with a TFW key. For example, a platform that uses a hardware based TEE can have attestation data signed by a hardware protected TFW key.

   Location: Device secure storage

   Supported Key Type: RSA and ECC

   Issuer: OEM CA

   Trust Implication: A whitelist of FW root CA trusted by TAMs

   Cardinality: One per device

2. TEE key pair and certificate: It is used for device attestation to a remote TAM and SP.
This key pair is burned into the device at device manufacturer. The key pair and its certificate are valid for the expected lifetime of the device.

Location: Device TEE

Supported Key Type: RSA and ECC

Issuer: A CA that chains to a TEE root CA

Trust Implication: A whitelist of TEE root CA trusted by TAMs

Cardinality: One per device

3. TAM key pair and certificate: A TAM provider acquires a certificate from a CA that a TEE trusts.

Location: TAM provider

Supported Key Type: RSA and ECC.

Supported Key Size: RSA 2048-bit, ECC P-256 and P-384. Other sizes should be anticipated in future.

Issuer: TAM CA that chains to a root CA

Trust Implication: A whitelist of TAM root CA embedded in TEE

Cardinality: One or multiple can be used by a TAM

4. SP key pair and certificate: an SP uses its own key pair and certificate to sign a TA.

Location: SP

Supported Key Type: RSA and ECC

Supported Key Size: RSA 2048-bit, ECC P-256 and P-384. Other sizes should be anticipated in future.

Issuer: an SP signer CA that chains to a root CA

Trust Implication: TAM manages SP. TA trusts an SP by validating trust against a TAM that the SP uses. A TEE trusts TAM to ensure that a TA from the TAM is trustworthy.

Cardinality: One or multiple can be used by an SP
5. Protocol Scope and Entity Relations

This document specifies messages and key properties that can establish mutual trust between a TEE and a TAM. The protocol provides specifications for the following three entities:

1. Key and certificate types required for device firmware, TEEs, TAs, SPs, and TAMs

2. Data message formats that should be exchanged between a TEE in a device and a TAM

3. An OTrP Broker in the REE that can relay messages between a Client Application and TEE

Figure 1: Protocol Scope and Entity Relationship

Figure 2: OTrP System Diagram
In the previous diagram, different Certificate Authorities can be used respectively for different types of certificates. OTrP Messages are always signed, where the signer keys is the message creator’s private key such as a FW’s private key, a TEE’s private key, or a TAM’s private key.

The main OTrP component consists of a set of standard JSON messages created by a TAM to deliver device SD and TA management commands to a device, and device attestation and response messages created by a TEE that responds to a TAM’s OTrP message.

The communication method of OTrP Messages between a TAM and TEE in a device may vary between TAM and TEE providers. A mandatory transport protocol is specified for a compliant TAM and a device TEE.

An OTrP Broker is used to bridge communication between a TAM and a TEE. The OTrP Broker doesn’t need to know the actual content of OTrP Messages except for the TEE routing information.
5.1. A Sample Device Setup Flow

Step 1: Prepare Images for Devices
1. [TEE vendor] Deliver TEE Image (CODE Binary) to device OEM
2. [CA] Deliver root CA Whitelist
3. [Soc] Deliver TFW Image

Step 2: Inject Key Pairs and Images to Devices
1. [OEM] Generate Secure Boot Key Pair (May be shared among multiple devices)
2. [OEM] Flash signed TFW Image and signed TEE Image onto devices (signed by Secure Boot Key)

Step 3: Setup attestation key pairs in devices
1. [OEM] Flash TFW Public Key and a bootloader key.
2. [TFW/TEE] Generate a unique attestation key pair and get a certificate for the device.

Step 4: Setup trust anchors in devices
1. [TFW/TEE] Store the key and certificate encrypted with the eFuse key
2. [TEE vendor or OEM] Store trusted CA certificate list into devices

5.2. Derived Keys in The Protocol

The protocol generates one key pair in run time to assist message communication and anonymous verification between a TAM and a TEE.

TEE SP Anonymous Key (AIK): one derived key pair per SP in a device

The purpose of the key pair is to sign data by a TEE without using its TEE device key for anonymous attestation to a Client Application. This key pair is generated in the first SD creation for an SP. It is deleted when all SDs are removed for a SP in a device. The public key of the key pair is given to the caller Client Application and TAM for future TEE returned data validation. The public key of this AIK is also used by a TAM to encrypt TA binary data and personalization data when it sends a TA to a device for installation.
5.3. Security Domain Hierarchy and Ownership

The primary job of a TAM is to help an SP to manage its trusted application components. A TA is typically installed in an SD. An SD is commonly created for an SP.

When an SP delegates its SD and TA management to a TAM, an SD is created on behalf of a TAM in a TEE and the owner of the SD is assigned to the TAM. An SD may be associated with an SP but the TAM has full privilege to manage the SD for the SP.

Each SD for an SP is associated with only one TAM. When an SP changes TAM, a new SP SD must be created to associate with the new TAM. The TEE will maintain a registry of TAM ID and SP SD ID mapping.

From an SD ownership perspective, the SD tree is flat and there is only one level. An SD is associated with its owner. It is up to TEE implementation how it maintains SD binding information for a TAM and different SPs under the same TAM.

It is an important decision in this protocol specification that a TEE doesn’t need to know whether a TAM is authorized to manage the SD for an SP. This authorization is implicitly triggered by an SP Client Application, which instructs what TAM it wants to use. An SD is always associated with a TAM in addition to its SP ID. A rogue TAM isn’t able to do anything on an unauthorized SP’s SD managed by another TAM.

Since a TAM may support multiple SPs, sharing the same SD name for different SPs creates a dependency in deleting an SD. An SD can be deleted only after all TAs associated with this SD is deleted. An SP cannot delete a Security Domain on its own with a TAM if a TAM decides to introduce such sharing. There are cases where multiple virtual SPs belong to the same organization, and a TAM chooses to use the same SD name for those SPs. This is totally up to the TAM implementation and out of scope of this specification.

5.4. SD Owner Identification and TAM Certificate Requirements

There is a need of cryptographically binding proof about the owner of an SD in a device. When an SD is created on behalf of a TAM, a future request from the TAM must present itself as a way that the TEE can verify it is the true owner. The certificate itself cannot reliably used as the owner because TAM may change its certificate.

To this end, each TAM will be associated with a trusted identifier defined as an attribute in the TAM certificate. This field is kept
the same when the TAM renew its certificates. A TAM CA is responsible to vet the requested TAM attribute value.

This identifier value must not collide among different TAM providers, and one TAM shouldn’t be able to claim the identifier used by another TAM provider.

The certificate extension name to carry the identifier can initially use SubjectAltName:registeredID. A dedicated new extension name may be registered later.

One common choice of the identifier value is the TAM’s service URL. A CA can verify the domain ownership of the URL with the TAM in the certificate enrollment process.

A TEE can assign this certificate attribute value as the TAM owner ID for the SDs that are created for the TAM.

An alternative way to represent an SD ownership by a TAM is to have a unique secret key upon SD creation such that only the creator TAM is able to produce a Proof-of-Possession (POP) data with the secret.

5.5. Service Provider Container

A sample Security Domain hierarchy for the TEE is shown below.

```
--- TEE ---
      |
      ---
      |   ---    |   ---
      |   |   |   |
      |   |   |   |
      |   |   |   |
      ---    ---
      |   ---    |
      |   |   |   |
      |   |   |   |
      ---    ---
      |   ---    |
      |   |   |   |
      |   |   |   |
      ---    ---
```

OTrP segregates SDs and TAs such that a TAM can only manage or retrieve data for SDs and TAs that it previously created for the SPs it represents.
6. OTrP Broker

A TEE and TAs that run inside the TEE don’t generally have capability to communicate to the outside of the hosting device, for example, the TEE specified by Global Platform groups [GPTEE]. This calls for a software module in the REE world to handle the network communication. Each Client Application in REE may carry this communication functionality but it must also interact with the TEE for the message exchange. The TEE interaction will vary according to different TEEs. In order for a Client Application to transparently support different TEEs, it is imperative to have a common interface for a Client Application to invoke for exchanging messages with TEEs.

A shared OTrP Broker comes to meet this need. An OTrP Broker is a Rich Application or SDK that facilitates communication between a TAM and TEE. It also provides interfaces for TAM SDK or Client Applications to query and trigger TA installation that the application needs to use.

This interface for Client Applications may be commonly an Android service call for an Android powered device. A Client Application interacts with a TAM, and turns around to pass messages received from TAM to OTrP Broker.

In all cases, a Client Application needs to be able to identify an OTrP Broker that it can use.

6.1. Role of OTrP Broker

An OTrP Broker abstracts the message exchanges with the TEE in a device. The input data is originated from a TAM that a Client Application connects. A Client Application may also directly call OTrP Broker for some TA query functions.

OTrP Broker may internally process a request from TAM. At least, it needs to know where to route a message, e.g. TEE instance. It doesn’t need to process or verify message content.

OTrP Broker returns TEE / TFW generated response messages to the caller. OTrP Broker isn’t expected to handle any network connection with an application or TAM.

OTrP Broker only needs to return an OTrP Broker error message if the TEE is not reachable for some reason. Other errors are represented as response messages returned from the TEE which will then be passed to the TAM.
6.2. OTrP Broker and Global Platform TEE Client API

A Client Application may use Global Platform (GP) TEE API for TA communication. OTrP may use the GP TEE Client API but it is internal to OTrP implementation that converts given messages from TAM. More details can be found at [GPTEECLAPI].

6.3. OTrP Broker Implementation Consideration

A Provider should consider methods of distribution, scope and concurrency on device and runtime options when implementing an OTrP Broker. Several non-exhaustive options are discussed below. Providers are encouraged to take advantage of the latest communication and platform capabilities to offer the best user experience.

6.3.1. OTrP Broker Distribution

OTrP Broker installation is commonly carried out at OEM time. A user can dynamically download and install an OTrP Broker on-demand.

It is important to ensure a legitimate OTrP Broker is installed and used. If an OTrP Broker is compromised it may send rogue messages to TAM and TEE and introduce additional risks.

6.3.2. Number of OTrP Broker

We anticipate only one shared OTrP Broker instance in a device. The device’s TEE vendor will most probably supply one OTrP Broker. Potentially we expect some open source.

With one shared OTrP Broker, the OTrP Broker provider is responsible to allow multiple TAMs and TEE providers to achieve interoperability. With a standard OTrP Broker interface, TAM can implement its own SDK for its SP Client Applications to work with this OTrP Broker.

Multiple independent OTrP Broker providers can be used as long as they have standard interface to a Client Application or TAM SDK. Only one OTrP Broker is expected in a device.

TAM providers are generally expected to provide SDK for SP applications to interact with an OTrP Broker for the TAM and TEE interaction.
6.4. OTrP Broker Interfaces for Client Applications

A Client Application shall be responsible for relaying messages between the OTrP Broker and the TAM.

If a failure occurs during calling OTrP Broker, an error message described in "Common Errors" section (see Section 7.6) will be returned.

6.4.1. ProcessOTrPMessage call

Description

A Client Application will use this method of the OTrP Broker in a device to pass OTrP messages from a TAM. The method is responsible for interacting with the TEE and for forwarding the input message to the TEE. It also returns TEE generated response message back to the Client Application.

Inputs:

TAMInMsg - OTrP message generated in a TAM that is passed to this method from a Client Application.

Outputs:

A TEE-generated OTrP response message (which may be a successful response or be a response message containing an error raised within the TEE) for the client application to forward to the TAM. In the event of the OTrP Broker not being able to communicate with the TEE, a OTrPBrokerException shall be thrown.

6.4.2. GetTAInformation call

Description

A Client Application may quickly query local TEE about a previously installed TA without requiring TAM each time if it has had the TA’s identifier and previously saved TEE SP AIK public key for TA information integrity verification.

Inputs:
The OTrP Broker is expected to return TA signer and TAM signer certificate along with other metadata information about the TA associated with the given identifier. It follows the underlying TEE trust model for authoring the local TA query from a Client Application.

The output is a JSON message that is generated by the TEE. It contains the following information:

* tamid
* SP ID
* TA signer certificate
* TAM certificate

The message is signed with TEE SP AIK private key.

The Client Application is expected to consume the response as follows.

The Client Application gets signed TA metadata, in particular, the TA signer certificate. It is able to verify that the result is from device by checking signer against TEE SP AIK public key it gets in some earlier interaction with TAM.

If this is a new Client Application in the device that hasn’t had TEE SP AIK public key for the response verification, the application can contact the TAM first to do GetDeviceState, and TAM will return TEE SP AIK public key to the app for this operation to proceed.

Output Message:
{ "TAInformationTBS": {
    "taid": "<TA Identifier from the input>",
    "tamid": "<TAM ID for the Security Domain where this TA resides>",
    "spid": "<The service provider identifier of this TA>",
    "signercert": "<The BASE64 encoded certificate data of the TA binary application’s signer certificate>",
    "signercacerts": [ < The full list of CA certificate chain including the root CA>
    ],
    "cacert": "<The BASE64 encoded CA certificate data of the TA binary application’s signer certificate>
    
    "tamcert": "<The BASE64 encoded certificate data of the TAM that manages this TA>",
    "tamcacerts": [ < The full list of CA certificate chain including the root CA>
    ],
    "cacert": "<The BASE64 encoded CA certificate data of the TAM that manages this TA>">
    
    "TAInformation": {
        "payload": "<The BASE64URL encoding of the TAInformationTBS JSON above>",
        "protected": "<BASE64URL encoded signing algorithm>",
        "header": {
            "signer": "<JWK definition of the TEE SP AIK public key>")
        },
        "signature": "<signature contents signed by TEE SP AIK private key BASE64URL encoded>"
    }
}

where the definitions of BASE64 and BASE64URL refer to [RFC4648].

A sample JWK public key representation refers to an example in [RFC7517].
6.5. Sample End-to-End Client Application Flow

6.5.1. Case 1: A New Client Application Uses a TA

1. During the Client Application installation time, the Client Application calls TAM to initialize the device preparation step.

   A. The Client Application knows it wants to use a Trusted Application TA1 but the application doesn’t know whether TA1 has been installed or not. It can use GP TEE Client API [GPTEECLAPI] to check the existence of TA1 first. If it detects that TA1 doesn’t exist, it will contact TAM to initiate the installation of TA1. Note that TA1 could have been previously installed by other Client Applications from the same service provider in the device.

   B. The Client Application sends the TAM the TA list that it depends on. The TAM will query a device for the Security Domains and TAs that have been installed, and instructs the device to install any dependent TAs that have not been installed.

   C. In general, the TAM has the latest TA list and their status in a device because all operations are instructed by TAM. TAM has such visibility because all Security Domain deletion and TA deletion are managed by the TAM; the TAM could have stored the state when a TA is installed, updated and deleted. There is also the possibility that an update command is carried out inside TEE but a response is never received in TAM. There is also possibility that some manual local reset is done in a device that the TAM isn’t aware of the changes.

2. The TAM generates message: GetDeviceStateRequest

3. The Client Application passes the JSON message GetDeviceStateRequest to OTrP Broker call ProcessOTrPMessage. The communication between a Client Application and an OTrP Broker is up to the implementation of the OTrP Broker.

4. The OTrP Broker routes the message to the active TEE. Multiple TEE case: it is up to OTrP Broker to figure this out. This specification limits the support to only one active TEE, which is the typical case today.

5. The target active TEE processes the received OTrP message, and returns a JSON message GetDeviceStateResponse.
6. The OTrP Broker passes the GetDeviceStateResponse to the Client Application.

7. The Client Application sends GetDeviceStateResponse to the TAM.

8. The TAM processes the GetDeviceStateResponse.
   
   A. Extract TEEspaik for the SP, signs TEEspaik with TAM signer key
   
   B. Examine SD list and TA list

9. The TAM continues to carry out other actions based on the need. The next call could be instructing the device to install a dependent TA.
   
   A. Assume a dependent TA isn’t in the device yet, the TAM may do the following: (1) create an SD in which to install the TA by sending a CreateSDRequest message. The message is sent back to the Client Application, and then the OTrP Broker and TEE to process; (2) install a TA with an InstallTARequest message.
   
   B. If a Client Application depends on multiple TAs, the Client Application should expect multiple round trips of the TA installation message exchanges.

10. At the last TAM and TEE operation, the TAM returns the signed TEE SP AIK public key to the application.

11. The Client Application stores the TEEspaik for future loaded TA trust check.

12. If the TAM finds that this is a fresh device that does not have any SD for the SP yet, then the TAM may next create an SD for the SP.

13. During Client Application installation, the application checks whether required Trusted Applications are already installed, which may have been provided by the TEE. If needed, it will contact its TAM service to determine whether the device is ready or install TA list that this application needs.

6.5.2. Case 2: A Previously Installed Client Application Calls a TA

1. The Client Application checks the device readiness: (a) whether it has a TEE; (b) whether it has TA that it depends. It may happen that TAM has removed the TA this application depends on.
2. The Client Application calls the OTrP Broker to query the TA.

3. The OTrP Broker queries the TEE to get TA information. If the given TA doesn’t exist, an error is returned.

4. The Client Application parses the TAInformation message.

5. If the TA doesn’t exist, the Client Application calls its TAM to install the TA. If the TA exists, the Client Application proceeds to call the TA.

7. OTrP Messages

The main OTrP component is the set of standard JSON messages created by a TAM to deliver device SD and TA management commands to a device, and device attestation and response messages created by TEE to respond to TAM OTrP Messages.

An OTrP Message is designed to provide end-to-end security. It is always signed by its creator. In addition, an OTrP Message is typically encrypted such that only the targeted device TEE or TAM is able to decrypt and view the actual content.

7.1. Message Format

OTrP Messages use the JSON format for JSON’s simple readability and moderate data size in comparison with alternative TLV and XML formats. More compact CBOR format may be used as an alternative choice.

JSON Message security has developed JSON Web Signing and JSON Web Encryption standard in the IETF Workgroup JOSE, see JWS [RFC7515] and JWE [RFC7516]. The OTrP Messages in this protocol will leverage the basic JWS and JWE to handle JSON signing and encryption.

7.2. Message Naming Convention

For each TAM command "xyz"", OTrP use the following naming convention to represent its raw message content and complete request and response messages:
7.3. Request and Response Message Template

An OTrP Request message uses the following format:

```
{
    "<name>TBSRequest": {
        <request message content>
    }
}
```

A corresponding OTrP Response message will be as follows.

```
{
    "<name>TBSResponse": {
        <response message content>
    }
}
```

7.4. Signed Request and Response Message Structure

A signed request message will generally include only one signature, and uses the flattened JWS JSON Serialization Syntax, see Section 7.2.2 in [RFC7515].

A general JWS object looks like the following.

```
{
    "payload": "<payload contents>",
    "protected": "<integrity-protected header contents>",
    "header": {
        <non-integrity-protected header contents>,
    },
    "signature": "<signature contents>"
}
```
OTrP signed messages only require the signing algorithm as the mandate header in the property "protected". The "non-integrity-protected header contents" is optional.

OTrP signed message will be given an explicit Request or Response property name. In other words, a signed Request or Response uses the following template.

A general JWS object looks like the following.

```
{  
  "<name>[Request | Response]": {  
    "payload": "<payload contents of <name>TBS[Request | Response]>",  
    "protected": "<integrity-protected header contents>",  
    "header": "<non-integrity-protected header contents>",  
    "signature": "<signature contents>"  
  }  
}
```

With the standard JWS message format, a signed OTrP Message looks like the following.

```
{  
  "<name>[Request | Response]": {  
    "payload": "<payload contents of <name>TBS[Request | Response]>",  
    "protected": "<integrity-protected header contents>",  
    "header": "<non-integrity-protected header contents>",  
    "signature": "<signature contents>"  
  }  
}
```

The top element "<name>[Signed][Request|Response]" cannot be fully trusted to match the content because it doesn’t participate in the signature generation. However, a recipient can always match it with the value associated with the property "payload". It purely serves to provide a quick reference for reading and method invocation.

Furthermore, most properties in an unsigned OTrP messages are encrypted to provide end-to-end confidentiality. The only OTrP message that isn’t encrypted is the initial device query message that asks for the device state information.

Thus a typical OTrP Message consists of an encrypted and then signed JSON message. Some transaction data such as transaction ID and TEE information may need to be exposed to the OTrP Broker for routing purpose. Such information is excluded from JSON encryption. The device’s signer certificate itself is encrypted. The overall final message is a standard signed JSON message.

As required by JSW/JWE, those JWE and JWS related elements will be BASE64URL encoded. Other binary data elements specific to the OTrP
specification are BASE64-encoded. This specification indicates elements that should be BASE64 and those elements that are to be BASE64URL encoded.

7.4.1. Identifying Signing and Encryption Keys for JWS/JWE Messaging

JWS and JWE messaging allow various options for identifying the signing and encryption keys, for example, it allows optional elements including "x5c", "x5t" and "kid" in the header to cover various possibilities.

To protect privacy, it is important that the device’s certificate is released only to a trusted TAM, and that it is encrypted. The TAM will need to know the device certificate, but untrusted parties must not be able to get the device certificate. All OTrP messaging conversations between a TAM and device begin with GetDeviceStateRequest / GetDeviceStateResponse. These messages have elements built into them to exchange signing certificates, described in the section Section 9. Any subsequent messages in the conversation that follow on from this implicitly use the same certificates for signing/encryption, and as a result the certificates or references may be omitted in those subsequent messages.

In other words, the signing key identifier in the use of JWS and JWE here may be absent in the subsequent messages after the initial GetDeviceState query.

This has an implication on the TEE and TAM implementation: they have to cache the signer certificates for the subsequent message signature validation in the session. It may be easier for a TAM service to cache transaction session information but not so for a TEE in a device. A TAM can get a device’s capability by checking the response message from a TEE to decide whether it should include its TAM signer certificate and OCSP data in each subsequent request message. The device’s caching capability is reported in GetDeviceStateResponse signerreq parameter.

7.5. JSON Signing and Encryption Algorithms

The OTrP JSON signing algorithm shall use SHA256 or a stronger hash method with respective key type. JSON Web Algorithm RS256 or ES256 [RFC7518] SHALL be used for RSA with SHA256 and ECDSA with SHA256. If RSA with SHA256 is used, the JSON web algorithm representation is as follows.

{"alg":"RS256"}
The (BASE64URL encoded) "protected" header property in a signed message looks like the following:

"protected":"eyJhbGciOiJSUzI1NiJ9"

If ECSDA with P-256 curve and SHA256 are used for signing, the JSON signing algorithm representation is as follows.

{"alg":"ES256"}

The value for the "protected" field will be the following.

eyJhbGciOiJFUzI1NiJ9

eyJhbGciOiJFUzI1NiJ9

Thus, a common OTrP signed message with ES256 looks like the following.

{
  "payload": "<payload contents>",
  "protected": "eyJhbGciOiJFUzI1NiJ9",
  "signature": "<signature contents>"
}

The OTrP JSON message encryption algorithm SHOULD use one of the supported algorithms defined in the later chapter of this document. JSON encryption uses a symmetric key as its "Content Encryption Key (CEK)". This CEK is encrypted or wrapped by a recipient’s key. The OTrP recipient typically has an asymmetric key pair. Therefore, the CEK will be encrypted by the recipient’s public key.

A compliant implementation shall support the following symmetric encryption algorithm and anticipate future new algorithms.

{"enc":"A128CBC-HS256"}

This algorithm represents encryption with AES 128 in CBC mode with HMAC SHA 256 for integrity. The value of the property "protected" in a JWE message will be

eyJlbmMiOiJBMTI4Q0JDLUhTMjU2In0
An encrypted JSON message looks like the following.

```json
{
  "protected": "eyJlbmMiOiJBMTI4Q0JDLUhTMjU2In0",
  "recipients": [
    {
      "header": {
        "alg": "<RSA1_5 etc.>>"
      },
      "encrypted_key": "<encrypted value of CEK>"
    }
  ],
  "iv": "<BASE64URL encoded IV data>",
  "ciphertext": "<Encrypted data over the JSON plaintext (BASE64URL)>",
  "tag": "<JWE authentication tag (BASE64URL)>"
}
```

OTrP doesn’t use JWE AAD (Additional Authenticated Data) because each message is always signed after the message is encrypted.

7.5.1. Supported JSON Signing Algorithms

The following JSON signature algorithm is mandatory support in the TEE and TAM:

- RS256
- ES256 is optional to support.

7.5.2. Support JSON Encryption Algorithms

The following JSON authenticated encryption algorithm is mandatory support in TEE and TAM.

- A128CBC-HS256
- A256CBC-HS512 is optional to support.

7.5.3. Supported JSON Key Management Algorithms

The following JSON key management algorithm is mandatory support in TEE and TAM.

- RSA1_5
- ECDH-ES+A128KW and ECDH-ES+A256KW are optional to support.
7.6. Common Errors

An OTrP Response message typically needs to report the operation status and error causes if an operation fails. The following JSON message elements should be used across all OTrP Messages.

"status": "pass | fail"

"reason": {
  "error-code": "<error code if there is any>",
  "error-message": "<error message>"
}

"ver": "<version string>"

7.7. OTrP Message List

The following table lists the OTrP commands and therefore corresponding Request and Response messages defined in this specification. Additional messages may be added in the future when new task messages are needed.

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GetDeviceState</td>
<td>A TAM queries a device’s current state with a message GetDeviceStateRequest. A device TEE will report its version, its FW version, and list of all SDs and TAs in the device that is managed by the requesting TAM. TAM may determine whether the device is trustworthy and decide to carry out additional commands according to the response from this query.</td>
</tr>
<tr>
<td>CreateSD</td>
<td>A TAM instructs a device TEE to create an SD for an SP. The recipient TEE will check whether the requesting TAM is trustworthy.</td>
</tr>
<tr>
<td>UpdateSD</td>
<td>A TAM instructs a device TEE to update an existing SD. A typical update need comes from SP certificate change, TAM certificate change and so on. The recipient TEE will verify whether the TAM is trustworthy and owns the SD.</td>
</tr>
<tr>
<td>DeleteSD</td>
<td>A TAM instructs a device TEE to delete an existing SD. A TEE conditionally deletes TAs loaded in the SD according to a request parameter. An SD cannot be deleted until all TAs in this SD are deleted. If this is the last SD for an SP, TEE MAY also delete TEE SP AIK key for this SP.</td>
</tr>
</tbody>
</table>
InstallTA –
A TAM instructs a device to install a TA into an SD for a SP. The TEE in a device will check whether the TAM and TA are trustworthy.

UpdateTA –
A TAM instructs a device to update a TA into an SD for an SP. The change may commonly be bug fix for a previously installed TA.

DeleteTA –
A TAM instructs a device to delete a TA. The TEE in a device will check whether the TAM and TA are trustworthy.

7.8. OTrP Request Message Routing Rules

For each command that a TAM wants to send to a device, the TAM generates a request message. This is typically triggered by a Client Application that uses the TAM. The Client Application initiates contact with the TAM and receives TAM OTrP Request messages according to the TAM’s implementation. The Client Application forwards the OTrP message to an OTrP Broker in the device, which in turn sends the message to the active TEE in the device.

The current version of this specification assumes that each device has only one active TEE, and the OTrP Broker is responsible to connect to the active TEE. This is the case today with devices in the market.

When the TEE responds to a request, the OTrP Broker gets the OTrP response messages back to the Client Application that sent the request. In case the target TEE fails to respond to the request, the OTrP Broker will be responsible to generate an error message to reply the Client Application. The Client Application forwards any data it received to its TAM.

7.8.1. SP Anonymous Attestation Key (SP AIK)

When the first new Security Domain is created in a TEE for an SP, a new key pair is generated and associated with this SP. This key pair is used for future device attestation to the service provider instead of using the device’s TEE key pair.

8. Transport Protocol Support

The OTrP message exchange between a TEE device and TAM generally takes place between a Client Application in REE and TAM. A device that is capable to run a TEE and PKI based cryptographic attestation
isn’t generally resource constraint to carry out standard HTTPS connections. A compliant device and TAM SHOULD support HTTPs.

9. Detailed Messages Specification

For each message in the following sections all JSON elements are mandatory if not explicitly indicated as optional.

9.1. GetDeviceState

This is the first command that a TAM will send to a device. This command is triggered when an SP’s Client Application contacts its TAM to check whether the underlying device is ready for TA operations.

This command queries a device’s current TEE state. A device TEE will report its version, its FW version, and list of all SDs and TAs in the device that is managed by the requesting TAM. TAM may determine whether the device is trustworthy and decide to carry out additional commands according to the response from this query.

The request message of this command is signed by the TAM. The response message from the TEE is encrypted. A random message encryption key (MK) is generated by TEE, and this encrypted key is encrypted by the TAM’s public key such that only the TAM that sent the request is able to decrypt and view the response message.

9.1.1. GetDeviceStateRequest message

```json
{
  "GetDeviceStateTBSRequest": {
    "ver": "1.0",
    "rid": "<Unique request ID>",
    "tid": "<transaction ID>",
    "ocspdat": [
      "<a list of OCSP stapling data>"
    ],
    "supportedsigalgs": [<array of supported signing algorithms>]
  }
}
```

The request message consists of the following data elements:

- **ver** - version of the message format
- **rid** - a unique request ID generated by the TAM
- **tid** - a unique transaction ID to trace request and response. This can be from a prior transaction’s tid field, and can be used in subsequent message exchanges in this TAM session. The combination of rid and tid MUST be made unique.
ocspdat – A list of OCSP stapling data respectively for the TAM certificate and each of the CA certificates up to the root certificate. The TAM provides OCSP data such that a recipient TEE can validate the TAM certificate chain revocation status without making its own external OCSP service call. A TEE MAY cache the CA OCSP data such that the array may contain only the OCSP stapling data for the TAM certificate in subsequent exchanges. This is a mandatory field.

supportedsigalgs – an optional property to list the signing algorithms that the TAM is able to support. A recipient TEE MUST choose an algorithm in this list to sign its response message if this property is present in a request. If it is absent, the TEE may use any compliant signing algorithm that is listed as mandatory support in this specification.

The final request message is JSON signed message of the above raw JSON data with TAM’s certificate.

```json
{
  "GetDeviceStateRequest": {
    "payload": "<BASE64URL encoding of the GetDeviceStateTBSRequest JSON above>",
    "protected": "<BASE64URL encoded signing algorithm>",
    "header": {
      "x5c": "<BASE64 encoded TAM certificate chain up to the root CA certificate>",
      "signature": "<signature contents signed by TAM private key>"
    }
  }
}
```

The signing algorithm SHOULD use SHA256 with respective key type. The mandatory algorithm support is the RSA signing algorithm. The signer header "x5c" is used to include the TAM signer certificate up to the root CA certificate.

9.1.2. Request processing requirements at a TEE

Upon receiving a request message GetDeviceStateRequest at a TEE, the TEE MUST validate a request:

1. Validate JSON message signing. If it doesn’t pass, an error message is returned.
2. Validate that the request TAM certificate is chained to a trusted CA that the TEE embeds as its trust anchor.
* Cache the CA OCSP stapling data and certificate revocation check status for other subsequent requests.

* A TEE can use its own clock time for the OCSP stapling data validation.

3. Optionally collect Firmware signed data

* This is a capability in ARM architecture that allows a TEE to query Firmware to get FW signed data. It isn't required for all TEE implementations. When TFW signed data is absent, it is up to a TAM's policy how it will trust a TEE.

4. Collect SD information for the SD owned by this TAM

9.1.3. Firmware Signed Data

Firmware isn’t expected to process or produce JSON data. It is expected to just sign some raw bytes of data.

The data to be signed by TFW key needs be some unique random data each time. The (UTF-8 encoded) "tid" value from the GetDeviceStateTBSRequest shall be signed by the firmware. TAM isn’t expected to parse TFW data except the signature validation and signer trust path validation.

It is possible that a TEE can get some valid TFW signed data from another device. The TEE is responsible to validate TFW integrity to ensure that the underlying device firmware is trustworthy. In some cases, a TEE isn’t able to get a TFW signed data, in which case the TEE trust validation is up to a TAM to decide. A TAM may opt to trust a TEE basing on the TEE signer and additional information about a TEE out-of-band.

When TFW signed data is available, a TAM validates the TEE and trusts that a trusted TEE has carried out appropriate trust check about a TFW.

TfwData: {
  "tbs": "<TFW to be signed data, BASE64 encoded>",
  "cert": "<BASE64 encoded TFW certificate>",
  "sigalg": "Signing method",
  "sig": "<TFW signed data, BASE64 encoded>"
}

It is expected that a FW uses standard signature methods for maximal interoperability with TAM providers. The mandatory support list of signing algorithm is RSA with SHA256.

The JSON object above is constructed by a TEE with data returned from the FW. It isn’t a standard JSON signed object. The signer information and data to be signed must be specially processed by a TAM according to the definition given here. The data to be signed is the raw data.

9.1.3.1. Supported Firmware Signature Methods

TAM providers shall support the following signature methods. A firmware provider can choose one of the methods in signature generation.

- RSA with SHA256
- ECDSA with SHA 256

The value of "sigalg" in the TfwData JSON message SHOULD use one of the following:

- RS256
- ES256

9.1.4. Post Conditions

Upon successful request validation, the TEE information is collected. There is no change in the TEE in the device.

The response message shall be encrypted where the encryption key shall be a symmetric key that is wrapped by TAM’s public key. The JSON Content Encryption Key (CEK) is used for this purpose.

9.1.5. GetDeviceStateResponse Message

The message has the following structure.

```javascript
{
    "GetDeviceTEEStateTBSResponse": {
        "ver": "1.0",
        "status": "pass | fail",
        "rid": "<the request ID from the request message>",
        "tid": "<the transaction ID from the request message>",
        "signerreq": true | false // about whether TAM needs to send signer data again in subsequent messages,
        "edsi": "<Encrypted JSON DSI information>"
    }
}
```
where

signerreq - true if the TAM should send its signer certificate and OCSP data again in the subsequent messages. The value may be "false" if the TEE caches the TAM’s signer certificate and OCSP status.

rid - the request ID from the request message

tid - the tid from the request message

edsi - the main data element whose value is JSON encrypted message over the following Device State Information (DSI).

The Device State Information (DSI) message consists of the following.
The encrypted JSON message looks like the following.

```json
{
  "dsi": {
    "tfwdata": {
      "tbs": "<TFW to be signed data is the tid>",
      "cert": "<BASE64 encoded TFW certificate>",
      "sigalg": "Signing method",
      "sig": "<TFW signed data, BASE64 encoded>",
    },
    "tee": {
      "name": "<TEE name>",
      "ver": "<TEE version>",
      "cert": "<BASE64 encoded TEE cert>",
      "cacert": "<JSON array value of CA certificates up to the root CA>",
      "sdlist": {
        "cnt": "<Number of SD owned by this TAM>",
        "sd": [
          {
            "name": "<SD name>",
            "spid": "<SP owner ID of this SD>",
            "talist": [
              {
                "taid": "<TA application identifier>",
                "taname": "<TA application friendly name>" // optional
              }
            ]
          }
        ],
        "teeaiklist": [
          {
            "spaik": "<SP AIK public key, BASE64 encoded>",
            "spaiktype": "<RSA | ECC>",
            "spid": "<sp id>",
          }
        ]
      }
    }
  }
}
```

The encrypted JSON message looks like the following.
{ "protected": "<BASE64URL encoding of encryption algorithm header JSON data>",
"recipients": [
   { "header": { "alg": "RSA1_5" },
   "encrypted_key": "<encrypted value of CEK>" 
 },
"iv": "<BASE64URL encoded IV data>",
"ciphertext": "<Encrypted data over the JSON object of dsi (BASE64URL)>",
"tag": "<JWE authentication tag (BASE64URL)>"
],

Assume we encrypt plaintext with AES 128 in CBC mode with HMAC SHA 256 for integrity, the encryption algorithm header is:

{"enc":"A128CBC-HS256"}

The value of the property "protected" in the above JWE message will be

eyJlbmMiOiJBMTI4Q0JDLUhTMjU2In0

In other words, the above message looks like the following:

{ "protected": "eyJlbmMiOiJBMTI4Q0JDLUhTMjU2In0",
"recipients": [
   { "header": { "alg": "RSA1_5" },
   "encrypted_key": "<encrypted value of CEK>" 
 },
"iv": "<BASE64URL encoded IV data>",
"ciphertext": "<Encrypted data over the JSON object of dsi (BASE64URL)>",
"tag": "<JWE authentication tag (BASE64URL)>"
]

The full response message looks like the following:
The CEK will be encrypted by the TAM public key in the device. The TEE signed message has the following structure.

```json
{
    "GetDeviceTEESecurityResponse": {
        "payload": "<BASE64URL encoding of the JSON message GetDeviceTEESecurityResponse>",
        "protected": "<BASE64URL encoding of signing algorithm>",
        "signature": "<BASE64URL encoding of the signature value>"
    }
}
```

The signing algorithm shall use SHA256 with respective key type, see Section 7.5.1.

The final GetDeviceStateResponse response message consists of an array of TEE responses.
9.1.6. Error Conditions

An error may occur if a request isn’t valid or the TEE runs into some error. The list of possible error conditions is the following.

- **ERR_REQUEST_INVALID**  The TEE meets the following conditions with a request message: (1) The request from a TAM has an invalid message structure; mandatory information is absent in the message; or an undefined member or structure is included. (2) TEE fails to verify the signature of the message or fails to decrypt its contents.

- **ERR_UNSUPPORTED_MSG_VERSION**  The TEE receives a version of message that the TEE can’t deal with.

- **ERR_UNSUPPORTED_CRYPTO_ALG**  The TEE receives a request message encoded with a cryptographic algorithm that the TEE doesn’t support.

- **ERR_TFW_NOT_TRUSTED**  The TEE considers the underlying device firmware be not trustworthy.

- **ERR_TAM_NOT_TRUSTED**  The TEE needs to make sure whether the TAM is trustworthy by checking the validity of the TAM certificate and OCSP stapling data and so on. If the TEE finds the TAM is not reliable, it returns this error code.

- **ERR_TEE_FAIL**  If the TEE fails to process a request because of its internal error but is able to sign an error response message, it will return this error code.

- **ERR_AGENT_TEE_FAIL**  The TEE failed to respond to a TAM request. The OTrP Broker will construct an error message in responding to the TAM’s request. The error message will not be signed.

The response message will look like the following if the TEE signing can work to sign the error response message.
"GetDeviceTEEStateTBSResponse": {
    "ver": "1.0",
    "status": "fail",
    "rid": "<the request ID from the request message>",
    "tid": "<the transaction ID from the request message>",
    "reason": {"error-code": "<error code>"}
    "supportedsigalgs": [<an array of signature algorithms that
the TEE supports>]
}

where

supportedsigalgs - an optional property to list the JWS signing
algorithms that the active TEE supports. When a TAM sends a
signed message that the TEE isn’t able to validate, it can
include signature algorithms that it is able to consume in this
status report. A TAM can generate a new request message to retry
the management task with a TEE-supported signing algorithm.

If the TEE isn’t able to sign an error message due to an internal
device error, a general error message should be returned by the OTrP
Broker.

9.1.7. TAM Processing Requirements

Upon receiving a GetDeviceStateResponse message at a TAM, the TAM
MUST validate the following.

- Parse to get list of GetDeviceTEEStateResponse JSON objects
- Parse the JSON "payload" property and decrypt the JSON element
  "edsi". The decrypted message contains the TEE signer
  certificate.
- Validate the GetDeviceTEEStateResponse JSON signature. The signer
  certificate is extracted from the decrypted message in the last
  step.
- Extract TEE information and check it against its TEE acceptance
  policy.
- Extract the TFW signed element, and check the signer and data
  integration against its TFW policy.
- Check the SD list and TA list and prepare for a subsequent command
  such as "CreateSD" if it needs to have a new SD for an SP.
9.2. Security Domain Management

9.2.1. CreateSD

This command is typically preceded with a GetDeviceState command that has acquired the device information of the target device by the TAM. The TAM sends such a command to instruct a TEE to create a new Security Domain for an SP.

A TAM sends an OTrP CreateSDRequest Request message to a device TEE to create a Security Domain for an SP. Such a request is signed by the TAM where the TAM signer may or may not be the same as the SP’s TA signer certificate. The resulting SD is associated with two identifiers for future management:

  o TAM as the owner. The owner identifier is a registered unique TAM ID that is stored in the TAM certificate.

  o SP identified by its TA signer certificate as the authorization. A TAM can add more than one SP certificate to an SD.

A Trusted Application that is signed by a matching SP signer certificate for an SD is eligible to be installed into that SD. The TA installation into an SD by a subsequent InstallTARequest message may be instructed from a TAM.

9.2.1.1. CreateSDRequest Message
The request message for CreateSD has the following JSON format.

```
{
  "CreateSDTBSRequest": {
    "ver": "1.0",
    "rid": "<unique request ID>",
    "tid": "<transaction ID>" // this may be from prior message
    "tee": "<TEE routing name from the DSI for the SD's target>",
    "nextdsi": true | false,
    "dsihash": "<hash of DSI returned in the prior query>",
    "content": ENCRYPTED { // this piece of JSON data will be
        // encrypted
        "spid": "<SP ID value>",
        "sdname": "<SD name for the domain to be created>",
        "spcert": "<BASE64 encoded SP certificate>",
        "tamid": "<An identifiable attribute of the TAM certificate>",
        "did": "<SHA256 hash of the TEE cert>"
    }
  }
}
```

In the message,

- **rid** - A unique value to identify this request
- **tid** - A unique value to identify this transaction. It can have the same value for the tid in the preceding GetDeviceStateRequest.
- **tee** - TEE ID returned from the previous GetDeviceStateResponse.
- **nextdsi** - Indicates whether the up-to-date Device State Information (DSI) is expected in the response from the TEE to this request.
- **dsihash** - The BASE64-encoded SHA256 hash value of the DSI data returned in the prior TAM operation with this target TEE. This value is always included such that a receiving TEE can check whether the device state has changed since its last query. It helps enforce SD update order in the right sequence without accidentally overwriting an update that was done simultaneously.
- **content** - The "content" is a JSON encrypted message that includes actual input for the SD creation. The encryption key is TAMmk that is encrypted by the target TEE’s public key. The entire message is signed by the TAM private key TAMpriv. A separate TAMmk isn’t used in the latest specification because JSON encryption will use a content encryption key for exactly the same purpose.
spid - A unique id assigned by the TAM for its SP. It should be unique within a TAM namespace.

sdname - a name unique to the SP. TAM should ensure it is unique for each SP.

spcert - The SP’s TA signer certificate is included in the request. This certificate will be stored by the device TEE which uses it to check against TA installation. Only if a TA is signed by a matching spcert associated with an SD will the TA be installed into the SD.

tamid - SD owner claim by TAM - an SD owned by a TAM will be associated with a trusted identifier defined as an attribute in the signer TAM certificate. TEE will be responsible to assign this ID to the SD. The TAM certificate attribute for this attribute tamid MUST be vetted by the TAM signer issuing CA. With this trusted identifier, the SD query at TEE can be fast upon TAM signer verification.

did - The SHA256 hash of the binary-encoded device TEE certificate. The encryption key CEK will be encrypted the recipient TEE’s public key. This hash value in the "did" property allows the recipient TEE to check whether it is the expected target to receive such a request. If this isn’t given, an OTrP message for device 2 could be sent to device 1. It is optional for the TEE to check because the successful decryption of the request message with this device’s TEE private key already proves it is the target. This explicit hash value makes the protocol not dependent on message encryption method in future.

A CreateSDTBSRequest message is signed to generate a final CreateSDRequest message as follows.

```json
{
  "CreateSDRequest": {
    "payload": "<CreateSDTBSRequest JSON above>",
    "protected": "<integrity-protected header contents>",
    "header": "<non-integrity-protected header contents>",
    "signature": "<signature contents signed by TAM private key>"
  }
}
```

The TAM signer certificate is included in the "header" property.
9.2.1.2. Request Processing Requirements at a TEE

Upon receiving a CreateSDRequest request message at a TEE, the TEE MUST do the following:

1. Validate the JSON request message as follows
   * Validate JSON message signing.
   * Validate that the request TAM certificate is chained to a trusted CA that the TEE embeds as its trust anchor.
   * Compare dsihash with its current state to make sure nothing has changed since this request was sent.
   * Decrypt to get the plaintext of the content: (a) spid, (b) sd name, (c) did.
   * Check that an SPID is supplied.
   * spcert check: check it is a valid certificate (signature and format verification only).
   * Check "did" is the SHA256 hash of its TEEcert BER raw binary data.
   * Check whether the requested SD already exists for the SP.
   * Check that the tamid in the request matches the TAM certificate’s TAM ID attribute.

2. If the request was valid, create action
   * Create an SD for the SP with the given name.
   * Assign the tamid from the TAMCert to this SD.
   * Assign the SPID and SPCert to this SD.
   * Check whether a TEE SP AIK key pair already exists for the given SP ID.
   * Create TEE SP AIK key pair if it doesn’t exist for the given SP ID.
   * Generate new DSI data if the request asks for updated DSI.

3. Construct a CreateSDResponse message
* Create raw content
  + Operation status
  + "did" or full signer certificate information,
  + TEE SP AIK public key if DSI isn’t going to be included
  + Updated DSI data if requested

* The response message is encrypted with the same JWE CEK of the request without recreating a new content encryption key.

* The encrypted message is signed with TEEpriv. The signer information ("did" or TEEcert) is encrypted.

4. Deliver the response message. (a) The OTrP Broker returns this to the Client Application; (b) The Client App passes this back to the TAM.

5. TAM processing. (a) The TAM processes the response message; (b) the TAM can look up signer certificate from the device ID "did".

   If a request is illegitimate or signature doesn’t pass, a "status" property in the response will indicate the error code and cause.

9.2.1.3. CreateSDResponse Message

The response message for a CreateSDRequest contains the following content.

```json
{
  "CreateSDTBSResponse": {
    "ver": "1.0",
    "status": "<operation result>",
    "rid": "<the request ID received>",
    "tid": "<the transaction ID received>",
    "content": ENCRYPTED {
      "reason": "<failure reason detail>", // optional
      "did": "<the device id received from the request>",
      "sdname": "<SD name for the domain created>",
      "teespaik": "<TEE SP AIK public key, BASE64 encoded>",
      "dsi": "<Updated TEE state, including all SDs owned by this TAM>"
    }
  }
}
```
In the response message, the following fields MUST be supplied.

**did** - The SHA256 hash of the device TEE certificate. This shows the device ID explicitly to the receiving TAM.

**teespaik** - The newly generated SP AIK public key for the given SP. This is an optional value if the device has had another domain for the SP that has triggered TEE SP AIK key pair for this specific SP.

There is a possible extreme error case where the TEE isn’t reachable or the TEE final response generation itself fails. In this case, the TAM might still receive a response from the OTrP Broker if the OTrP Broker is able to detect such error from TEE. In this case, a general error response message should be returned by the OTrP Broker, assuming OTrP Broker even doesn’t know any content and information about the request message.

In other words, the TAM should expect to receive a TEE successfully signed JSON message, a general "status" message, or none when a client experiences a network error.

```json
{
  "CreateSDResponse": {
    "payload": "<CreateSDTBSResponse JSON above>",
    "protected": {
      "<BASE64URL of signing algorithm>"
    },
    "signature": "<signature contents signed by the TEE device private key (BASE64URL)>"
  }
}
```

A response message type "status" will be returned when the TEE fails to respond. The OTrP Broker is responsible to create this message.

```json
{
  "status": {
    "result": "fail",
    "error-code": "ERR_AGENT_TEE_FAIL",
    "error-message": "TEE fails to respond"
  }
}
```
9.2.1.4. Error Conditions

An error might occur if a request isn’t valid or the TEE runs into some error. The list of possible errors are as follows. Refer to the Error Code List (Section 13.1) for detailed causes and actions.

- ERR_AGENT_TEE_BUSY
- ERR_AGENT_TEE_FAIL
- ERR_AGENT_TEE_UNKNOWN
- ERR_REQUEST_INVALID
- ERR_UNSUPPORTED_MSG_VERSION
- ERR_UNSUPPORTED_CRYPTO_ALG
- ERR_DEV_STATE_MISMATCH
- ERR_SD_ALREADY_EXIST
- ERR_SD_NOT_FOUND
- ERR_SPCERT_INVALID
- ERR_TEE_FAIL
- ERR_TAM_NOTAUTHORIZED
- ERR_TAM_NOT_TRUSTED

9.2.2. UpdateSD

This TAM initiated command can update an SP’s SD that it manages for any of the following needs: (a) Update an SP signer certificate; (b) Add an SP signer certificate when an SP uses multiple to sign TA binaries; (c) Update an SP ID.

The TAM presents the proof of the SD ownership to the TEE, and includes related information in its signed message. The entire request is also encrypted for end-to-end confidentiality.

9.2.2.1. UpdateSDRequest Message
The UpdateSD request message has the following JSON format.

```json
{
  "UpdateSDTBSRequest": {
    "ver": "1.0",
    "rid": "<unique request ID>",
    "tid": "<transaction ID>", // this may be from prior message
    "tee": "<TEE routing name from the DSI for the SD’s target>",
    "nextdsi": true | false,
    "dsihash": "<hash of DSI returned in the prior query>",
    "content": ENCRYPTED { // this piece of JSON will be encrypted
      "tamid": "<tamid associated with this SD>",
      "spid": "<SP ID>",
      "sdname": "<SD name for the domain to be updated>",
      "changes": {
        "newsdname": "<Change the SD name to this new name>", // Optional
        "newspid": "<Change SP ID of the domain to this new value>", // Optional
        "spcert": ["<BASE64 encoded new SP signer cert to be added>"], // Optional
        "deloldspcert": ["<The SHA256 hex value of an old SP cert assigned into this SD that should be deleted >"],
        // Optional
        "renewteespaik": true | false
      }
    }
  }
}
```

In the message,

rid - A unique value to identify this request

tid - A unique value to identify this transaction. It can have the same value as the tid in the preceding GetDeviceStateRequest.

tee - TEE ID returned from the previous GetDeviceStateResponse

nextdsi - Indicates whether the up-to-date Device State Information (DSI) is expected to be returned in the response from the TEE to this request.

dsihash - The BASE64-encoded SHA256 hash value of the DSI data returned in the prior TAM operation with this target TEE. This value is always included such that a receiving TEE can check whether the device state has changed since its last query. It
helps enforce SD update order in the right sequence without accidentally overwriting an update that was done simultaneously.

**content** - The "content" is a JSON encrypted message that includes actual input for the SD update. The standard JSON content encryption key (CEK) is used, and the CEK is encrypted by the target TEE’s public key.

**tamid** - SD owner claim by TAM - an SD owned by a TAM will be associated with a trusted identifier defined as an attribute in the signer TAM certificate.

**spid** - the identifier of the SP whose SD will be updated. This value is still needed because the SD name is considered unique only within an SP.

**sdname** - the name of the target SD to be updated.

**changes** - its content consists of changes are to be updated in the given SD.

**newsdname** - the new name of the target SD to be assigned if this value is present.

**newspid** - the new SP ID of the target SD to be assigned if this value is present.

**spcert** - a new TA signer certificate of this SP to be added to the SD if this is present.

**deloldspcert** - an SP certificate assigned into the SD is to be deleted if this is present. The value is the SHA256 fingerprint of the old SP certificate.

**renewteespaik** - the value should be true or false. If it is present and the value is true, the TEE MUST regenerate TEE SP AIK for this SD’s owner SP. The newly generated TEE SP AIK for the SP must be returned in the response message of this request. If there is more than one SD for the SP, a new SPID for one of the domains will always trigger a new teespaik generation as if a new SP were introduced to the TEE.
The UpdateSDTBSRequest message is signed to generate the final UpdateSDRequest message.

```json
{
    "UpdateSDRequest": {
        "payload": "<UpdateSDTBSRequest JSON above>",
        "protected": "<integrity-protected header contents>",
        "header": "<non-integrity-protected header contents>",
        "signature": "<signature contents signed by TAM private key>"
    }
}
```

TAM signer certificate is included in the "header" property.

9.2.2.2. Request Processing Requirements at a TEE

Upon receiving a request message UpdateSDRequest at a TEE, the TEE must validate a request:

1. Validate the JSON request message
   * Validate JSON message signing
   * Validate that the request TAM certificate is chained to a trusted CA that the TEE embeds as its trust anchor. The TAM certificate status check is generally not needed anymore in this request. The prior request should have validated the TAM certificate’s revocation status.
   * Compare dsihash with the TEE cached last response DSI data to this TAM.
   * Decrypt to get the plaintext of the content.
   * Check that the target SD name is supplied.
   * Check whether the requested SD exists.
   * Check that the TAM owns this TAM by verifying tamid in the SD matches TAM certificate’s TAM ID attribute.
   * Now the TEE is ready to carry out update listed in the "content" message.

2. If the request is valid, update action
   * If "newsdname" is given, replace the SD name for the SD to the new value
* If "newspid" is given, replace the SP ID assigned to this SD with the given new value
* If "spcert" is given, add this new SP certificate to the SD.
* If "deloldspcert" is present in the content, check previously assigned SP certificates to this SD, and delete the one that matches the given certificate hash value.
* If "renewteespaik" is given and has a value of 'true', generate a new TEE SP AIK key pair, and replace the old one with this.
* Generate new DSI data if the request asks for updated DSI
* Now the TEE is ready to construct the response message

3. Construct UpdateSDResponse message
* Create raw content
  + Operation status
  + "did" or full signer certificate information,
  + TEE SP AIK public key if DSI isn’t going to be included
  + Updated DSI data if requested
* The response message is encrypted with the same JWE CEK of the request without recreating a new content encryption key.
* The encrypted message is signed with TEEpriv. The signer information ("did" or TEEcert) is encrypted.

4. Deliver response message. (a) The OTrP Broker returns this to the app; (b) The app passes this back to the TAM.

5. TAM processing. (a) The TAM processes the response message; (b) The TAM can look up the signer certificate from the device ID "did".

If a request is illegitimate or the signature doesn’t pass, a "status" property in the response will indicate the error code and cause.
9.2.2.3. UpdateSDResponse Message

The response message for a UpdateSDRequest contains the following content.

```json
{
  "UpdateSDTBSResponse": {
    "ver": "1.0",
    "status": "<operation result>",
    "rid": "<the request ID received>",
    "tid": "<the transaction ID received>",
    "content": ENCRYPTED {
      "reason": "<failure reason detail>", // optional
      "did": "<the device id hash>",
      "cert": "<TEE certificate>", // optional
      "teespaik": "<TEE SP AIK public key, BASE64 encoded>",
      "teespaiktype": "<TEE SP AIK key type: RSA or ECC>",
      "dsi": "<Updated TEE state, including all SD owned by this TAM>
    }
  }
}
```

In the response message, the following fields MUST be supplied.

did - The request should have known the signer certificate of this device from a prior request. This hash value of the device TEE certificate serves as a quick identifier only. A full device certificate isn’t necessary.

teespaik - the newly generated SP AIK public key for the given SP if the TEE SP AIK for the SP is asked to be renewed in the request. This is an optional value if "dsi" is included in the response, which will contain all up-to-date TEE SP AIK key pairs.

Similar to the template for the creation of the encrypted and signed CreateSDResponse, the final UpdateSDResponse looks like the following.
A response message type "status" will be returned when the TEE fails to respond. The OTrP Broker is responsible to create this message.

```json
{  "status": {  "result": "fail",  "error-code": "ERR_AGENT_TEE_FAIL",  "error-message": "<TEE fails to respond message>"  }
}
```

9.2.2.4. Error Conditions

An error may occur if a request isn’t valid or the TEE runs into some error. The list of possible errors are as follows. Refer to the Error Code List (Section 13.1) for detailed causes and actions.

- ERR_AGENT_TEE_BUSY
- ERR_AGENT_TEE_FAIL
- ERR_AGENT_TEE_UNKNOWN
- ERR_REQUEST_INVALID
- ERR_UNSUPPORTED_MSG_VERSION
- ERR_UNSUPPORTED_CRYPTO_ALG
- ERR_DEV_STATE_MISMATCH
- ERR_SD_NOT_FOUND
- ERR_SDNAME_ALREADY_USED
- ERR_SPCERT_INVALID
9.2.3. DeleteSD

A TAM sends a DeleteSDRequest message to a TEE to delete a specified SD that it owns. An SD can be deleted only if there is no TA associated with this SD in the device. The request message can contain a flag to instruct the TEE to delete all related TAs in an SD and then delete the SD.

The target TEE will operate with the following logic.

1. Look up the given SD specified in the request message
2. Check that the TAM owns the SD
3. Check that the device state hasn’t changed since the last operation
4. Check whether there are TAs in this SD
5. If TA exists in an SD, check whether the request instructs whether the TA should be deleted. If the request instructs the TEE to delete TAs, delete all TAs in this SD. If the request doesn’t instruct the TEE to delete TAs, return an error "ERR_SD_NOT_EMPTY".
6. Delete the SD
7. If this is the last SD of this SP, delete the TEE SP AIK key.

9.2.3.1. DeleteSDRequest Message
The request message for DeleteSD has the following JSON format.

```
{
    "DeleteSDTBSRequest": {
        "ver": "1.0",
        "rid": "<unique request ID>",
        "tid": "<transaction ID>", // this may be from prior message
        "tee": "<TEE routing name from the DSI for the SD’s target>",
        "nextdsi": true | false,
        "dsihash": "<hash of DSI returned in the prior query>",
        "content": ENCRYPTED { // this piece of JSON will be encrypted
            "tamid": "<tamid associated with this SD>",
            "sdname": "<SD name for the domain to be updated>",
            "deleteta": true | false
        }
    }
}
```

In the message,

- `rid` - A unique value to identify this request
- `tid` - A unique value to identify this transaction. It can have the same value for the tid in the preceding GetDeviceStateRequest.
- `tee` - TEE ID returned from the previous response GetDeviceStateResponse
- `nextdsi` - Indicates whether the up-to-date Device State Information (DSI) is to be returned in the response to this request.
- `dsihash` - The BASE64-encoded SHA256 hash value of the DSI data returned in the prior TAM operation with this target TEE. This value is always included such that a receiving TEE can check whether the device state has changed since its last query. It helps enforce SD update order in the right sequence without accidentally overwriting an update that was done simultaneously.
- `content` - The "content" is a JSON encrypted message that includes actual input for the SD update. The standard JSON content encryption key (CEK) is used, and the CEK is encrypted by the target TEE’s public key.
- `tamid` - SD owner claim by TAM - an SD owned by a TAM will be associated with a trusted identifier defined as an attribute in the signer TAM certificate.
- `sdname` - the name of the target SD to be updated.
deleteta - the value should be boolean ‘true’ or ‘false’. If it is present and the value is ‘true’, the TEE should delete all TAs associated with the SD in the device.

According to the OTrP message template, the full request DeleteSDRequest is a signed message over the DeleteSDTBSRequest as follows.

{  "DeleteSDRequest": {    "payload": "<DeleteSDTBSRequest JSON above>",    "protected": "<integrity-protected header contents>",    "header": "<non-integrity-protected header contents>",    "signature": "<signature contents signed by TAM private key>"  }
}

TAM signer certificate is included in the "header" property.

9.2.3.2. Request Processing Requirements at a TEE

Upon receiving a request message DeleteSDRequest at a TEE, the TEE must validate a request:

1. Validate the JSON request message
   * Validate JSON message signing
     * Validate that the request TAM certificate is chained to a trusted CA that the TEE embeds as its trust anchor. The TAM certificate status check is generally not needed anymore in this request. The prior request should have validated the TAM certificate’s revocation status.
     * Compare dshash with the TEE cached last response DSI data to this TAM
     * Decrypt to get the plaintext of the content
     * Check that the target SD name is supplied
     * Check whether the requested SD exists
     * Check that the TAM owns this TAM by verifying that the tamid in the SD matches the TAM certificate’s TAM ID attribute
     * Now the TEE is ready to carry out the update listed in the "content" message
2. If the request is valid, deletion action
   * Check TA existence in this SD
   * If "deleteta" is "true", delete all TAs in this SD. If the value of "deleteta" is false and some TA exists, return an error "ERR_SD_NOT_EMPTY"
   * Delete the SD
   * Delete the TEE SP AIK key pair if this SD is the last one for the SP
   * Now the TEE is ready to construct the response message
3. Construct a DeleteSDResponse message
   * Create response content
     + Operation status
     + "did" or full signer certificate information,
     + Updated DSI data if requested
   * The response message is encrypted with the same JWE CEK of the request without recreating a new content encryption key.
   * The encrypted message is signed with TEEpriv. The signer information ("did" or TEEcert) is encrypted.
4. Deliver response message. (a) The OTrP Broker returns this to the app; (b) The app passes this back to the TAM
5. TAM processing. (a) The TAM processes the response message; (b) The TAM can look up signer certificate from the device ID "did".

If a request is illegitimate or the signature doesn’t pass, a "status" property in the response will indicate the error code and cause.

9.2.3.3. DeleteSDResponse Message

The response message for a DeleteSDRequest contains the following content.
In the response message, the following fields MUST be supplied.

did - The request should have known the signer certificate of this device from a prior request. This hash value of the device TEE certificate serves as a quick identifier only. A full device certificate isn’t necessary.

The final DeleteSDResponse looks like the following.

```
{  
    "DeleteSDResponse": {  
        "payload": "<DeleteSDTBSResponse JSON above>",  
        "protected": {  
            "<BASE64URL of signing algorithm>"  
        },  
        "signature": "<signature contents signed by TEE device private key (BASE64URL)>"  
    }  
}  
```

A response message type "status" will be returned when the TEE fails to respond. The OTrP Broker is responsible to create this message.

```
{  
    "status": {  
        "result": "fail",  
        "error-code": "ERR_AGENT_TEE_FAIL",  
        "error-message": "TEE fails to respond"  
    }  
}  
```
9.2.3.4. Error Conditions

An error may occur if a request isn’t valid or the TEE runs into some error. The list of possible errors is as follows. Refer to the Error Code List (Section 13.1) for detailed causes and actions.

ERR_AGENT_TEE_BUSY
ERR_AGENT_TEE_FAIL
ERR_AGENT_TEE_UNKNOWN
ERR_REQUEST_INVALID
ERR_UNSUPPORTED_MSG_VERSION
ERR_UNSUPPORTED_CRYPTO_ALG
ERR_DEV_STATE_MISMATCH
ERR_SD_NOT_EMPTY
ERR_SD_NOT_FOUND
ERR_TEE_FAIL
ERR_TAM_NOT_AUTHORIZED
ERR_TAM_NOT_TRUSTED

9.3. Trusted Application Management

This protocol doesn’t introduce a TA container concept. All TA authorization and management will be up to the TEE implementation.

The following three TA management commands are supported.

- InstallTA - provision a TA by TAM
- UpdateTA - update a TA by TAM
- DeleteTA - remove TA registration information with an SD, remove the TA binary and all TA-related data in a TEE
9.3.1. InstallTA

TA binary data and related personalization data if there is any can be from two sources:

1. A TAM supplies the signed and encrypted TA binary
2. A Client Application supplies the TA binary

This specification primarily considers the first case where a TAM supplies a TA binary. This is to ensure that a TEE can properly validate whether a TA is trustworthy. Further, TA personalization data will be encrypted by the TEE device’s SP public key for end-to-end protection. A Client Application bundled TA case will be addressed separately later.

A TAM sends the following information in a InstallTARequest message to a target TEE:

- The target SD information: SP ID and SD name
- Encrypted TA binary data. TA data is encrypted with the TEE SP AIK.
- TA metadata. It is optional to include the SP signer certificate for the SD to add if the SP has changed signer since the SD was created.

The TEE processes the command given by the TAM to install a TA into an SP’s SD. It does the following:

- Validation
  * The TEE validates the TAM message authenticity
  * Decrypt to get request content
  * Look up the SD with the SD name
  * Checks that the TAM owns the SD
  * Checks that the DSI hash matches which shows that the device state hasn’t changed

- If the request is valid, continue to do the TA validation
  * Decrypt to get the TA binary data and any personalization data with the "TEE SP AIK private key"
* Check that SP ID is the one that is registered with the SP SD

* Check that the TA signer is either a newly given SP certificate or the one that is already trusted by the SD from the previous TA installation. The TA signing method is specific to a TEE. This specification doesn’t define how a TA should be signed; a TAM should support TEE specific TA signing when it supports that TEE.

* If a TA signer is given in the request, add this signer into the SD.

  o If the above validation passed, continue to do TA installation

  * The TEE re-encrypts the TA binary and its personalization data with its own method.

  * The TEE enrolls and stores the TA in a secure storage.

  o Construct a response message. This involves signing encrypted status information for the requesting TAM.

9.3.1.1. InstallTARequest Message
The request message for InstallTA has the following JSON format.

```
{  
  "InstallTATBSRequest": {  
    "ver": "1.0",  
    "rid": "<unique request ID>",  
    "tid": "<transaction ID>",  
    "tee": "<TEE routing name from the DSI for the SD’s target>",  
    "nextdsi": true | false,  
    "dsihash": "<hash of DSI returned in the prior query>",  
    "content": ENCRYPTED {  
      "tamid": "<TAM ID previously assigned to the SD>",  
      "spid": "<SPID value>",  
      "sdname": "<SD name for the domain to install the TA>",  
      "spcert": "<BASE64 encoded SP certificate >", // optional  
      "taid": "<TA identifier>"  
    },  
    "encrypted_ta": {  
      "key": "<JWE enveloped data of a 256-bit symmetric key by  
             the recipient’s TEEspaik public key>",  
      "iv": "<hex of 16 random bytes>",  
      "alg": "<encryption algoritm. AESCBC by default.>",  
      "ciphertadata": "<BASE64 encoded encrypted TA binary data>",  
      "cipherpdata": "<BASE64 encoded encrypted TA personalization  
                      data>"  
    }  
  }  
}
```

In the message,

- **rid** - A unique value to identify this request.
- **tid** - A unique value to identify this transaction. It can have the same value for the tid in the preceding GetDeviceStateRequest.
- **tee** - TEE ID returned from the previous GetDeviceStateResponse.
- **nextdsi** - Indicates whether the up-to-date Device State Information (DSI) is to be returned in the response to this request.
- **dsihash** - The BASE64-encoded SHA256 hash value of the DSI data returned in the prior TAM operation with this target TEE. This value is always included such that a receiving TEE can check whether the device state has changed since its last query. It helps enforce SD update order in the right sequence without accidentally overwriting an update that was done simultaneously.
content - The "content" is a JSON encrypted message that includes actual input for the SD update. The standard JSON content encryption key (CEK) is used, and the CEK is encrypted by the target TEE’s public key.

tamid - SD owner claim by TAM - An SD owned by a TAM will be associated with a trusted identifier defined as an attribute in the signer TAM certificate.

spid - SP identifier of the TA owner SP

sdname - the name of the target SD where the TA is to be installed

spcert - an optional field to specify the SP certificate that signed the TA. This is sent if the SP has a new certificate that hasn’t been previously registered with the target SD where the TA should be installed.

taid - the identifier of the TA application to be installed

encrypted_ta - the message portion contains encrypted TA binary data and personalization data. The TA data encryption key is placed in "key", which is encrypted by the recipient’s public key, using JWE enveloped structure. The TA data encryption uses symmetric key based encryption such as AES_CBC.

According to the OTrP message template, the full request InstallTARequest is a signed message over the InstallTATBSRequest as follows.

```
{  "InstallTARequest": {    "payload": "<InstallTATBSRequest JSON above>",    "protected": "<integrity-protected header contents>",    "header": "<non-integrity-protected header contents>",    "signature": "<signature contents signed by TAM private key>"
  }
}
```

9.3.1.2. InstallTAResponse Message

The response message for a InstallTARequest contains the following content.

{  
  "InstallTATBSResponse": {  
    "ver": "1.0",
    "status": "<operation result>",
    "rid": "<the request ID received>",
    "tid": "<the transaction ID received>",
    "content": ENCRYPTED {  
      "reason": "<failure reason detail>", // optional
      "did": "<the device id hash>",
      "dsi": "<Updated TEE state, including all SD owned by this TAM>"
    }
  }
}

In the response message, the following fields MUST be supplied.

did - the SHA256 hash of the device TEE certificate. This shows the device ID explicitly to the receiving TAM.

The final message InstallTAResponse looks like the following.

{  
  "InstallTAResponse": {  
    "payload": "<InstallTATBSResponse JSON above>",
    "protected": {  
      "<BASE64URL of signing algorithm>"
    },
    "signature": "<signature contents signed by TEE device private key (BASE64URL)>"
  }
}

A response message type "status" will be returned when the TEE fails to respond. The OTrP Broker is responsible to create this message.

{  
  "status": {  
    "result": "fail",
    "error-code": "ERR_AGENT_TEE_FAIL",
    "error-message": "TEE fails to respond"
  }
}
9.3.1.3. Error Conditions

An error may occur if a request isn’t valid or the TEE runs into some error. The list of possible errors are as follows. Refer to the Error Code List (Section 13.1) for detailed causes and actions.

ERR_AGENT_TEE_BUSY
ERR_AGENT_TEE_FAIL
ERR_AGENT_TEE_UNKNOWN
ERR_REQUEST_INVALID
ERR_UNSUPPORTED_MSG_VERSION
ERR_UNSUPPORTED_CRYPTO_ALG
ERR_DEV_STATE_MISMATCH
ERR_SD_NOT_FOUND
ERR_TA_INVALID
ERR_TA_ALREADY_INSTALLED
ERR_TEE_FAIL
ERR_TEE_RESOURCE_FULL
ERR_TAM_NOT_AUTHORIZED
ERR_TAM_NOT_TRUSTED

9.3.2. UpdateTA

This TAM-initiated command can update a TA and its data in an SP’s SD that it manages for the following purposes.

1. Update TA binary
2. Update TA’s personalization data

The TAM presents the proof of the SD ownership to a TEE, and includes related information in its signed message. The entire request is also encrypted for end-to-end confidentiality.
The TEE processes the command from the TAM to update the TA of an SP SD. It does the following:

- Validation
  - The TEE validates the TAM message authenticity
  - Decrypt to get request content
  - Look up the SD with the SD name
  - Checks that the TAM owns the SD
  - Checks DSI hash matches that the device state hasn’t changed

- TA validation
  - Both TA binary and personalization data are optional, but at least one of them shall be present in the message
  - Decrypt to get the TA binary and any personalization data with the "TEE SP AIK private key"
  - Check that SP ID is the one that is registered with the SP SD
  - Check that the TA signer is either a newly given SP certificate or the one in SD.
  - If a TA signer is given in the request, add this signer into the SD.

- If the above validation passes, continue to do TA update
  - The TEE re-encrypts the TA binary and its personalization data with its own method
  - The TEE replaces the existing TA binary and its personalization data with the new binary and data.

- Construct a response message. This involves signing a encrypted status information for the requesting TAM.

9.3.2.1. UpdateTARequest Message
The request message for UpdateTA has the following JSON format.

```
"UpdateTATBSRequest": {
  "ver": "1.0",
  "rid": "<unique request ID>",
  "tid": "<transaction ID>",
  "tee": "<TEE routing name from the DSI for the SD’s target>",
  "nextdsi": true | false,
  "dsihash": "<hash of DSI returned in the prior query>",
  "content": ENCRYPTED {
    "tamid": "<TAM ID previously assigned to the SD>",
    "spid": "<SPID value>",
    "sdname": "<SD name for the domain to be created>",
    "spcert": "<BASE64 encoded SP certificate >", // optional
    "taid": "<TA identifier>
  },
  "encrypted_ta": {
    "key": "<JWE enveloped data of a 256-bit symmetric key by
           the recipient’s TEEspaik public key>",
    "iv": "<hex of 16 random bytes>",
    "alg": "<encryption algorithm. AESCBC by default.>",
    "ciphernewtadata": "<Change existing TA binary to this new TA
binary data(BASE64 encoded and encrypted)>",
    "ciphernewpdata": "<Change the existing data to this new TA
personalization data(BASE64 encoded and encrypted)>"
  } // optional
}
```

In the message,

- **rid** - A unique value to identify this request.
- **tid** - A unique value to identify this transaction. It can have the same value for the tid in the preceding GetDeviceStateRequest.
- **tee** - TEE ID returned from the previous GetDeviceStateResponse
- **nextdsi** - Indicates whether the up-to-date Device State Information (DSI) is to be returned in the response to this request.
- **dsihash** - The BASE64-encoded SHA256 hash value of the DSI data returned in the prior TAM operation with this target TEE. This value is always included such that a receiving TEE can check whether the device state has changed since its last query. It
helps enforce SD update order in the right sequence without accidentally overwriting an update that was done simultaneously.

content - The "content" is a JSON encrypted message that includes actual input for the SD update. The standard JSON content encryption key (CEK) is used, and the CEK is encrypted by the target TEE’s public key.

tamid - SD owner claim by TAM - an SD owned by a TAM will be associated with a trusted identifier defined as an attribute in the signer TAM certificate.

spid - SP identifier of the TA owner SP

spcert - an optional field to specify the SP certificate that signed the TA. This is sent if the SP has a new certificate that hasn’t been previously registered with the target SD where the TA is to be installed.

sdname - the name of the target SD where the TA should be updated

taid - an identifier for the TA application to be updated

encrypted_ta - the message portion contains newly encrypted TA binary data and personalization data.

According to the OTrP message template, the full request UpdateTARequest is a signed message over the UpdateTATBSRequest as follows.

```
{
  "UpdateTARequest": {
    "payload": "<UpdateTATBSRequest JSON above>",
    "protected": "<integrity-protected header contents>",
    "header": "<non-integrity-protected header contents>",
    "signature": "<signature contents signed by TAM private key>"
  }
}
```

9.3.2.2. UpdateTAResponse Message

The response message for a UpdateTARequest contains the following content.
In the response message, the following fields MUST be supplied.

did - the SHA256 hash of the device TEE certificate. This shows the device ID explicitly to the receiving TAM.

The final message UpdateTAResponse looks like the following.

```json
"UpdateTAResponse": {
   "payload":"<UpdateTATBSResponse JSON above>",
   "protected": {
      "<BASE64URL of signing algorithm>"
   },
   "signature": "<signature contents signed by TEE device private key (BASE64URL)>"
}
```

A response message type "status" will be returned when the TEE fails to respond. The OTrP Broker is responsible to create this message.

```json
"status": {
   "result": "fail",
   "error-code": "ERR_AGENT_TEE_FAIL",
   "error-message": "TEE fails to respond"
}
```
9.3.2.3. Error Conditions

An error may occur if a request isn’t valid or the TEE runs into some error. The list of possible errors are as follows. Refer to the Error Code List (Section 13.1) for detailed causes and actions.

ERR_AGENT_TEE_BUSY
ERR_AGENT_TEE_FAIL
ERR_AGENT_TEE_UNKNOWN
ERR_REQUEST_INVALID
ERR_UNSUPPORTED_MSG_VERSION
ERR_UNSUPPORTED_CRYPTO_ALG
ERR_DEV_STATE_MISMATCH
ERR_SD_NOT_FOUND
ERR_TA_INVALID
ERR_TA_NOT_FOUND
ERR_TEE_FAIL
ERR_TAM_NOT_AUTHORIZED
ERR_TAM_NOT_TRUSTED

9.3.3. DeleteTA

This operation defines OTrP messages that allow a TAM to instruct a TEE to delete a TA for an SP in a given SD. A TEE will delete a TA from an SD and also TA data in the TEE. A Client Application cannot directly access TEE or OTrP Broker to delete a TA.

9.3.3.1. DeleteTAResult Message
The request message for DeleteTA has the following JSON format.

```json
{
    "DeleteTATBSRequest": {
        "ver": "1.0",
        "rid": "<unique request ID>",
        "tid": "<transaction ID>",
        "tee": "<TEE routing name from the DSI for the SD’s target>",
        "nextdsi": true | false,
        "dsihash": "<hash of DSI returned in the prior query>",
        "content": ENCRYPTED {
            "tamid": "<TAM ID previously assigned to the SD>",
            "sdname": "<SD name of the TA>",
            "taid": "<the identifier of the TA to be deleted from the
            specified SD>"
        }
    }
}
```

In the message,

- **rid** - A unique value to identify this request
- **tid** - A unique value to identify this transaction. It can have the same value for the tid in the preceding GetDeviceStateRequest.
- **tee** - The TEE ID returned from the previous GetDeviceStateResponse
- **nextdsi** - Indicates whether the up-to-date Device State Information (DSI) is to be returned in the response to this request.
- **dsihash** - The BASE64-encoded SHA256 hash value of the DSI data returned in the prior TAM operation with this target TEE. This value is always included such that a receiving TEE can check whether the device state has changed since its last query. It helps enforce SD update order in the right sequence without accidentally overwriting an update that was done simultaneously.
- **content** - The "content" is a JSON encrypted message that includes actual input for the SD update. The standard JSON content encryption key (CEK) is used, and the CEK is encrypted by the target TEE’s public key.
- **tamid** - SD owner claim by TAM - an SD owned by a TAM will be associated with a trusted identifier defined as an attribute in the signer TAM certificate.
- **sdname** - the name of the target SD where the TA is installed
taid - an identifier for the TA application to be deleted

According to the OTrP message template, the full request DeleteTARequest is a signed message over the DeleteTATBSRequest as follows.

```json
{
    "DeleteTARequest": {
        "payload": "<DeleteTATBSRequest JSON above>",
        "protected": "<integrity-protected header contents>",
        "header": "<non-integrity-protected header contents>",
        "signature": "<signature contents signed by TAM private key>"
    }
}
```

9.3.3.2. Request Processing Requirements at a TEE

A TEE processes a command from a TAM to delete a TA of an SP SD. It does the following:

1. Validate the JSON request message
   * The TEE validates TAM message authenticity
   * Decrypt to get request content
   * Look up the SD and the TA with the given SD name and TA ID
   * Checks that the TAM owns the SD, and TA is installed in the SD
   * Checks that the DSI hash matches and the the device state hasn’t changed

2. Deletion action
   * If all the above validation points pass, the TEE deletes the TA from the SD
   * The TEE SHOULD also delete all personalization data for the TA

3. Construct DeleteTAResponse message.

If a request is illegitimate or the signature doesn’t pass, a "status" property in the response will indicate the error code and cause.
9.3.3.3. DeleteTAResponse Message

The response message for a DeleteTARequest contains the following content.

```
{  
  "DeleteTATBSResponse": {  
    "ver": "1.0",
    "status": "<operation result>",
    "rid": "<the request ID received>",
    "tid": "<the transaction ID received>",
    "content": ENCRYPTED {  
      "reason": "<failure reason detail>", // optional
      "did": "<the device id hash>",
      "dsi": "<Updated TEE state, including all SD owned by this TAM>"  
    }  
  }  
}
```

In the response message, the following fields MUST be supplied.

- **did** - the SHA256 hash of the device TEE certificate. This shows the device ID explicitly to the receiving TAM.

The final message DeleteTAResponse looks like the following.

```
{  
  "DeleteTAResponse": {  
    "payload": "<DeleteTATBSResponse JSON above>",
    "protected": {  
      "<BASE64URL of signing algorithm>"
    },
    "signature": "<signature contents signed by TEE device private key (BASE64URL)>"
  }  
}
```

A response message type "status" will be returned when the TEE fails to respond. The OTrP Broker is responsible to create this message.
9.3.3.4. Error Conditions

An error may occur if a request isn’t valid or the TEE runs into some error. The list of possible errors are as follows. Refer to the Error Code List (Section 13.1) for detailed causes and actions.

ERR_AGENT_TEE_BUSY
ERR_AGENT_TEE_FAIL
ERR_AGENT_TEE_UNKNOWN
ERR_REQUEST_INVALID
ERR_UNSUPPORTED_MSG_VERSION
ERR_UNSUPPORTED_CRYPTO_ALG
ERR_DEV_STATE_MISMATCH
ERR_SD_NOT_FOUND
ERR_TA_NOT_FOUND
ERR_TEE_FAIL
ERR_TAM_NOT_AUTHORIZED
ERR_TAM_NOT_TRUSTED

10. Response Messages a TAM May Expect

A TAM expects some feedback from a remote device when a request message is delivered to a device. The following three types of responses SHOULD be supplied.

Type 1: Expect a valid TEE-generated response message

A valid TEE signed response may contain errors detected by a TEE, e.g. a TAM is trusted but some TAM-supplied data is missing, for
example, SP ID doesn’t exist. TEE MUST be able to sign and encrypt.

If a TEE isn’t able to sign a response, the TEE returns an error to the OTrP Broker without giving any other internal information. The OTrP Broker will be generating the response.

Type 2: The OTrP Broker generated error message when TEE fails. OTrP Broker errors will be defined in this document.

A Type 2 message has the following format.

```json
{  "OTrPBrokerError": {    "ver": "1.0",    "rid": ",    "tid": ",    "errcode": "ERR_AGENT_TEE_UNKNOWN | ERR_AGENT_TEE_BUSY"  } }
```

Type 3: OTrP Broker itself isn’t reachable or fails. A Client Application is responsible to handle error and respond the TAM in its own way. This is out of scope for this specification.

11. Basic Protocol Profile

This section describes a baseline for interoperability among the protocol entities, mainly, the TAM and TEE.

A TEE MUST support RSA algorithms. It is optional to support ECC algorithms. A TAM SHOULD use a RSA certificate for TAM message signing. It may use an ECC certificate if it detects that the TEE supports ECC according to the field "supportedsignalgs" in a TEE response.

A TAM MUST support both RSA 2048-bit algorithm and ECC P-256 algorithms. With this, a TEE and TFW certificate can be either RSA or ECC type.

JSON signing algorithms

- RSA PKCS#1 with SHA256 signing : "RS256"
- ECDSA with SHA256 signing : "ES256"

JSON asymmetric encryption algorithms (describes key-exchange or key-agreement algorithm for sharing symmetric key with TEE):
12. Attestation Implementation Consideration

It is important to know that the state of a device is appropriate before trusting that a device is what it says it is. The attestation scheme for OTrP must also be able to cope with different TEEs, including those that are OTrP compliant and those that use another mechanism. In the initial version, only one active TEE is assumed.

It is out of scope how the TAM and the device implement the trust hierarchy verification. However, it is helpful to understand what each system provider should do in order to properly implement an OTrP trust hierarchy.

In this section, we provide some implementation reference consideration.

12.1. OTrP Trusted Firmware

12.1.1. Attestation signer

It is proposed that attestation for OTrP is based on the TFW layer, and that further attestation is not performed within the TEE itself during Security Domain operations. The rationale is that the device boot process will be defined to start with a secure bootloader protected with a harden key in eFUSE. The process releases attestation signing capabilities into the TFW once a trust boot has been established. In this way the release of the attestation signer can be considered the first "platform configuration metric", using Trust Computing Group (TCG) terminology.

12.1.2. TFW Initial Requirements

R1 The TFW must be possible for verification during boot

R2 The TFW must allow a public / private key pair to be generated during device manufacture
R3  The public key and certificate must be possible to store securely.

R4  The private key must be possible to store encrypted at rest.

R5  The private key must only be visible to the TFW when it is decrypted.

R6  The TFW must be able to read a list of root and intermediate certificates that it can use to check certificate chains with. The list must be stored such that it cannot be tampered with.

R7  Need to allow a TEE to access its unique TEE specific private key.

12.2. TEE Loading

During boot, the TFW is required to start all of the root TEEs. Before loading them, the TFW must first determine whether the code sign signature of the TEE is valid. If TEE integrity is confirmed, the TEE may be started. The TFW must then be able to receive the identity certificate from the TEE (if that TEE is OTrP compliant). The identity certificate and keys will need to be baked into the TEE image, and therefore also covered by the code signer hash during the manufacturing process. The private key for the identity certificate must be securely protected. The private key for a TEE identity must never be released no matter how the public key and certificate are released to the TFW.

Once the TFW has successfully booted a TEE and retrieved the identity certificate, the TFW will commit this to the platform configuration register (PCR) set, for later use during attestation. At minimum, the following data must be committed to the PCR for each TEE:

1. Public key and certificate for the TEE

2. TEE identifier that can be used later by a TAM to identify this TEE

12.3. Attestation Hierarchy

The attestation hierarchy and seed required for TAM protocol operation must be built into the device at manufacture. Additional TEEs can be added post-manufacture using the scheme proposed, but it is outside of the current scope of this document to detail that.

It should be noted that the attestation scheme described is based on signatures. The only decryption that may take place is through the use of a bootloader key.
12.3.1. Attestation Hierarchy Establishment: Manufacture

During manufacture the following steps are required:

1. A device-specific TFW key pair and certificate are burnt into the device. This key pair will be used for signing operations performed by the TFW.

2. TEE images are loaded and include a TEE instance-specific key pair and certificate. The key pair and certificate are included in the image and covered by the code signing hash.

3. The process for TEE images is repeated for any subordinate TEEs, which are additional TEEs after the root TEE that some devices have.

12.3.2. Attestation Hierarchy Establishment: Device Boot

During device boot the following steps are required:

1. The boot module releases the TFW private key by decrypting it with the bootloader key.

2. The TFW verifies the code-signing signature of the active TEE and places its TEE public key into a signing buffer, along with its identifier for later access. For a non-OTrP TEE, the TFW leaves the TEE public key field blank.

3. The TFW signs the signing buffer with the TFW private key.

4. Each active TEE performs the same operation as the TFW, building up their own signed buffer containing subordinate TEE information.

12.3.3. Attestation Hierarchy Establishment: TAM

Before a TAM can begin operation in the marketplace to support devices of a given TEE, it must obtain a TAM certificate from a CA that is registered in the trust store of devices with that TEE. In this way, the TEE can check the intermediate and root CA and verify that it trusts this TAM to perform operations on the TEE.

13. IANA Considerations

The error code listed in the next section will be registered.
13.1. Error Code List

This section lists error codes that could be reported by a TA or TEE in a device in responding to a TAM request, and a separate list that OTrP Broker may return when the TEE fails to respond.

13.1.1. TEE Signed Error Code List

ERR_DEV_STATE_MISMATCH - A TEE will return this error code if the DSI hash value from TAM doesn’t match the has value of the device’s current DSI.

ERR_SD_ALREADY_EXISTS - This error will occur if an SD to be created already exists in the TEE.

ERR_SD_NOT_EMPTY - This is reported if a target SD isn’t empty.

ERR_SDNAME_ALREADY_USED - A TEE will return this error code if the new SD name already exists in the TEE.

ERR_REQUEST_INVALID - This error will occur if the TEE meets any of the following conditions with a request message: (1) The request from a TAM has an invalid message structure; mandatory information is absent in the message. undefined member or structure is included. (2) TEE fails to verify signature of the message or fails to decrypt its contents.

ERR_SPCERT_INVALID - If a new SP certificate for the SD to be updated is not valid, then the TEE will return this error code.

ERR_TA_ALREADY_INSTALLED - While installing a TA, a TEE will return this error if the TA has already been installed in the SD.

ERR_TA_INVALID - This error will occur when a TEE meets any of the following conditions while checking validity of TA: (1) The TA binary has a format that the TEE can’t recognize. (2) The TEE fails to decrypt the encoding of the TA binary and personalization data. (3) If an SP isn’t registered with the SP SD where the TA will be installed.

ERR_TA_NOT_FOUND - This error will occur when the target TA doesn’t exist in the SD.

ERR_TEE_FAIL - If the TEE fails to process a request because of an internal error, it will return this error code.

ERR_TEE_RESOURCE_FULL - This error is reported when a device resource isn’t available anymore such as storage space is full.
ERR_TFW_NOT_TRUSTED - A TEE is responsible for determining that the underlying device firmware is trustworthy. If the TEE determines the TFW is not trustworthy, then this error will occur.

ERR_TAM_NOT_TRUSTED - Before processing a request, a TEE needs to make sure whether the sender TAM is trustworthy by checking the validity of the TAM certificate, etc. If the TEE finds that the TAM is not trustworthy, then it will return this error code.

ERR_UNSUPPORTED_CRYPTO_ALG - This error will occur if a TEE receives a request message encoded with cryptographic algorithms that the TEE doesn’t support.

ERR_UNSUPPORTED_MSG_VERSION - This error will occur if a TEE receives a message version that the TEE can’t deal with.

13.1.2. OTrP Broker Error Code List

ERR_AGENT_TEE_UNKNOWN - This error will occur if the receiver TEE is not supposed to receive the request. That will be determined by checking the TEE name or device id in the request message.

ERR_AGENT_TEE_BUSY - The device TEE is busy. The request can be generally sent again to retry.

ERR_AGENT_TEE_FAIL - The TEE fails to respond to a TAM request. The OTrP Broker will construct an error message in responding to the TAM’s request.

14. Security Consideration

14.1. Cryptographic Strength

The strength of the cryptographic algorithms, using the measure of ‘bits of security’ defined in NIST SP800-57 allowed for OTrP is:

- At a minimum, 112 bits of security. The limiting factor for this is the RSA-2048 algorithm, which is indicated as providing 112 bits of symmetric key strength in SP800-57. It is important that RSA is supported in order to enhance the interoperability of the protocol.

- The option exists to choose algorithms providing 128 bits of security. This requires using TEE devices that support ECC P256.

The available algorithms and key sizes specified in this document are based on industry standards. Over time the recommended or allowed cryptographic algorithms may change. It is important that the OTrP
allows for crypto-agility. In this specification, TAM and TEE can negotiate an agreed upon algorithm where both include their supported algorithm in OTrP message.

14.2. Message Security

OTrP messages between the TAM and TEE are protected by message security using JWS and JWE. The ‘Basic protocol profile’ section of this document describes the algorithms used for this. All OTrP TEE devices and OTrP TAMS must meet the requirements of the basic profile. In the future additional ‘profiles’ can be added.

PKI is used to ensure that the TEE will only communicate with a trusted TAM, and to ensure that the TAM will only communicate with a trusted TEE.

14.3. TEE Attestation

It is important that the TAM can trust that it is talking to a trusted TEE. This is achieved through attestation. The TEE has a private key and certificate built into it at manufacture, which is used to sign data supplied by the TAM. This allows the TAM to verify that the TEE is trusted.

It is also important that the TFW (trusted firmware) can be checked. The TFW has a private key and certificate built into it at manufacture, which allows the TEE to check that that the TFW is trusted.

The GetDeviceState message therefore allows the TAM to check that it trusts the TEE, and the TEE at this point will check whether it trusts the TFW.

14.4. TA Protection

A TA will be delivered in an encrypted form. This encryption is an additional layer within the message encryption described in the Section 11 of this document. The TA binary is encrypted for each target device with the device’s TEE SP AIK public key. A TAM can either do this encryption itself or provide the TEE SP AIK public key to an SP such that the SP encrypts the encrypted TA for distribution to the TEE.
The encryption algorithm can use a random AES 256 key "taek" with a 16 byte random IV, and the "taek" is encrypted by the "TEE SP AIK public key". The following encrypted TA data structure is expected by a TEE:

"encrypted_ta_bin": {
    "key": "<JWE enveloped data of a 256-bit symmetric key by
            the recipient’s TEEspaik public key>",
    "iv": "<hex of 16 random bytes>",
    "alg": "AESCBC",
    "cipherdata": "<BASE64 encoded encrypted TA binary data>"
}

14.5. TA Personalization Data

An SP or TAM can supply personalization data for a TA to initialize for a device. Such data is passed through an InstallTA command from a TAM. The personalization data itself is (or can be) opaque to the TAM. The data can be from the SP without being revealed to the TAM. The data is sent in an encrypted manner in a request to a device such that only the device can decrypt. A device’s TEE SP AIK public key for an SP is used to encrypt the data. Here JWE enveloping is used to carry all encryption key parameters along with encrypted data.

"encrypted_ta_data": { // "TA personalization data"
    "key": "<JWE enveloped data of a 256-bit symmetric key by
            the recipient’s TEEspaik public key>",
    "iv": "<hex of 16 random bytes>",
    "alg": "AESCBC",
    "cipherdata": "<BASE64 encoded encrypted TA personalization data>"
}

14.6. TA Trust Check at TEE

A TA binary is signed by a TA signer certificate. This TA signing certificate/private key belongs to the SP, and may be self-signed (i.e., it need not participate in a trust hierarchy). It is the responsibility of the TAM to only allow verified TAs from trusted SPs into the system. Delivery of that TA to the TEE is then the responsibility of the TEE, using the security mechanisms provided by the OTrP.

We allow a way for an (untrusted) application to check the trustworthiness of a TA. OTrP Broker has a function to allow a Client Application to query the information about a TA.
An application in the Rich O/S may perform verification of the TA by verifying the signature of the TA. The GetTAInformation function is available to return the TEE supplied TA signer and TAM signer information to the application. An application can do additional trust checks on the certificate returned for this TA. It might trust the TAM, or require additional SP signer trust chaining.

14.7. One TA Multiple SP Case

A TA for multiple SPs must have a different identifier per SP. A TA will be installed in a different SD for each respective SP.

14.8. OTrP Broker Trust Model

An OTrP Broker could be malware in the vulnerable REE. A Client Application will connect its TAM provider for required TA installation. It gets command messages from the TAM, and passes the message to the OTrP Broker.

The OTrP is a conduit for enabling the TAM to communicate with the device’s TEE to manage SDs and TAs. All TAM messages are signed and sensitive data is encrypted such that the OTrP Broker cannot modify or capture sensitive data.

14.9. OCSP Stapling Data for TAM Signed Messages

The GetDeviceStateRequest message from a TAM to a TEE shall include OCSP stapling data for the TAM’s signer certificate and for intermediate CA certificates up to the root certificate so that the TEE can verify the signer certificate’s revocation status.

A certificate revocation status check on a TA signer certificate is OPTIONAL by a TEE. A TAM is responsible for vetting a TA and the SP before it distributes them to devices. A TEE will trust a TA signer certificate’s validation status done by a TAM when it trusts the TAM.

14.10. Data Protection at TAM and TEE

The TEE implementation provides protection of data on the device. It is the responsibility of the TAM to protect data on its servers.

14.11. Privacy Consideration

Devices are issued with a unique TEE certificate to attest the device’s validity. This uniqueness also creates a privacy and tracking risk that must be mitigated.
The TEE will only release the TEE certificate to a trusted TAM (it must verify the TAM certificate before proceeding). OTrP is designed such that only a TAM can obtain the TEE device certificate and firmware certificate - the GetDeviceState message requires signature checks to validate the TAM is trusted, and OTrP delivers the device's certificate(s) encrypted such that only that TAM can decrypt the response. A Client Application will never see the device certificate.

An SP-specific TEE SP AIK (TEE SP Anonymous Key) is generated by the protocol for Client Applications. This provides a way for the Client Application to validate some data that the TEE may send without requiring the TEE device certificate to be released to the client device rich O/S, and to optionally allow an SP to encrypt a TA for a target device without the SP needing to be supplied with the TEE device certificate.

14.12. Threat Mitigation

A rogue application may perform excessive TA loading. An OTrP Broker implementation should protect against excessive calls.

Rogue applications might request excessive SD creation. The TAM is responsible to ensure this is properly guarded against.

Rogue OTrP Broker could replay or send TAM messages out of sequence: e.g., a TAM sends update1 and update2. The OTrP Broker replays update2 and update1 again, creating an unexpected result that a client wants. "dsihash" is used to mitigate this. The TEE MUST store DSI state and check that the DSI state matches before it does another update.

Concurrent calls from a TAM to a TEE MUST be handled properly by a TEE. If multiple concurrent TAM operations take place, these could fail due to the "dsihash" being modified by another concurrent operation. The TEE is responsible for resolve any locking such that one application cannot lock other applications from using the TEE, except for a short term duration of the TAM operation taking place. For example, an OTrP operation that starts but never completes (e.g. loss of connectivity) must not prevent subsequent OTrP messages from being executed.

14.13. Compromised CA

A root CA for TAM certificates might get compromised. Some TEE trust anchor update mechanism is expected from device OEMs. A compromised intermediate CA is covered by OCSP stapling and OCSP validation check
in the protocol. A TEE should validate certificate revocation about a TAM certificate chain.

If the root CA of some TEE device certificates is compromised, these devices might be rejected by a TAM, which is a decision of the TAM implementation and policy choice. Any intermediate CA for TEE device certificates SHOULD be validated by TAM with a Certificate Revocation List (CRL) or Online Certificate Status Protocol (OCSP) method.


The TEE SHOULD use validation of the supplied TAM certificates and OCSP stapled data to validate that the TAM is trustworthy.

Since PKI is used, the integrity of the clock within the TEE determines the ability of the TEE to reject an expired TAM certificate, or revoked TAM certificate. Since OCSP stapling includes signature generation time, certificate validity dates are compared to the current time.

14.15. Certificate Renewal

TFW and TEE device certificates are expected to be long lived, longer than the lifetime of a device. A TAM certificate usually has a moderate lifetime of 2 to 5 years. A TAM should get renewed or rekeyed certificates. The root CA certificates for a TAM, which are embedded into the trust anchor store in a device, should have long lifetimes that don’t require device trust anchor update. On the other hand, it is imperative that OEMs or device providers plan for support of trust anchor update in their shipped devices.

15. Acknowledgements

We thank Alin Mutu for his contribution to many discussion that helped to design the trust flow mechanisms, and the creation of the flow diagrams. We also thank the following people (in alphabetical order) for their input and review: Sangsu Baek, Rob Coombs, Dapeng Liu, Dave Thaler, and Pengfei Zhao.

16. References

16.1. Normative References

16.2. Informative References


Appendix A. Sample Messages

A.1. Sample Security Domain Management Messages

A.1.1. Sample GetDeviceState

A.1.1.1. Sample GetDeviceStateRequest

The TAM builds a "GetDeviceStateTBSRequest" message.
A.1.1.2. Sample GetDeviceStateResponse

The TAM sends "GetDeviceStateRequest" to the OTrP Broker.

The OTrP Broker obtains "dsi" from each TEE. (In this example there is a single TEE.)

The TEE obtains signed "fwdata" from firmware.

The TEE builds "dsi" - summarizing device state of the TEE.


The TEE encrypts "dsi", and embeds it into a "GetDeviceTEEStateTBSResponse" message.
{ "GetDeviceTEEStateTBSResponse": { "ver": "1.0", "status": "pass", "rid": "{8C6F9DBB-FC39-435c-BC89-4D3614DA2F0B}\"", "tid": "{4F454A7F-002D-4157-884E-B0DD1A06A8AE}\", "signerreq": "false", "edsi": { "protected": "eyJlbmMiOiJBMTI4Q0JDLUhTMjU2In0K", "recipients": [ { "header": { "alg": "RSA1_5" }, "encrypted_key": "QUVTMTI4IChDRUspIGtleSwgZW5jcnlwdGVkIHdpdGggVFNNIFJTQSBwdWJsaW5lZCIgY2xlc3QgZGVldGluZw" } ], "iv": "ySGmfZ69Y1cEi1N5_SGbA", "ciphertext": "c2FtcGxlIGRzaSBkYXRhIGVuY3J5cHRlZCB3aXRoIEFFUzEyOCBrZXkgZnJvbGllbnRzLmVuY3J5cHRlZF9rZXk", "tag": "c2FtcGxlIGF1dGhlbnRpY2F0aW9uIHRhZw" } } } The TEE signs "GetDeviceTEEStateTBSResponse" and returns it to the OTrP Broker. The OTrP Broker encodes "GetDeviceTEEStateResponse" into an array to form "GetDeviceStateResponse".
The TEE returns "GetDeviceStateResponse" back to the OTrp Broker, which returns message back to the TAM.

A.1.2. Sample CreateSD

A.1.2.1. Sample CreateSDRequest
{  "CreateSDTBSRequest": {    "ver": "1.0",    "rid": "req-01",    "tid": "tran-01",    "tee": "SecuriTEE",    "nextdsl": "false",    "dsihash": "Iu-c0-fGrpMmzbbtiWI1U87wMJE7IK8wkJpsVuf2js",    "content": {      "spid": "bank.com",      "sdbname": "sd.bank.com",      "spcert": "MIIDFjCCAn-gAwIBAgIJAIk0Tat0tquDMA0GCSqGSIb3DQEBBQUAMwxCzAAMBAAADgYDKwYB
BgEBAAMEAwIBAgIBADANBgkqhkiG9w0BAQsFADAdBgNVHMEgfzB9oXCkbjBaMQswCQYDVQQGEwJU
EyMwDQYJKoZIhvcNAQEFBQADggEAMCIG8GBQEBGgYDVR0lAQH_BAwwCgYIKwYBBQUHAwIwHDAi
BTANBgkqhkiG9w0BAQEFAAOCAwggAfMB0GCSqGSIb3DQEBCwUAA4GNADCBiQKBgQDD/a3Fhj+iN
vY+QvneAvyByBbJ8reo898O3p2Vp7ebcK+cmT/WzQW0a57BwEs55XxVxTTz0i/gx2IwBRdDT
820hp/HDNPQX3DcDq15+iKmzsvBZgUy8f5Tn/jizFAIksTVHI0lXwIPKjyZkplB5dt201w7F
11ZzGRWXXclc1L5KGY290OwIdQ",      "tamid": "TAM_x.acme.com",      "did": "zAHkb0-SQh9U_OT8mR5dB-tygcqpUJ9_x07pIiw8WoM"    }  }

Below is a sample message after the content is encrypted and encoded
Internet-Draft
OTRP
October 2018

dEpSvm1POGdkSe1tV29NSUVJRuxzVGthblZcb25wqkF4ZHE0ckVMb19T7lliaFg4z2mub2
gxUVUif0v0sImI2IjoiXhZqOERdDdJrRzZxYksdmasIzU9maUSIsImNpCQh1cnRleHQb1i1l
bmWVZXndmx55Xr3hZeW5q1FqRTJvNjvA0Hpe4N4d1b3nM3FETY0qY2F6NpbFY3Nlc1j
ZhHnjF5qzBu0bdoYnQJQXVrSmwXb5bTf02jGempU1ibBaTzYnVSMzg2zSUpRS1bj
UUVrU1kZ2tWX0NAZTM2eTVkDVBpFMBmc1g0zFk0b0dMEdavaWjVClyUV1VETY3BSwT
J1tZvUnYfnd0ydnT01kxYX2vdW02QWcataDb6y12T2GzvbhrRFVG2LVdPTXTZY0
JrZsR25hrRzZ2mBzlX01jWn1TNkR09wOVVrzdJfcQG0qSTjpedjkbwZ2uaXFCnvpxQVBxzd1
ajyW1V1QJQzPFT1NLZXEGTITYu3pqRh0idm1ntnTXNEAhwkszl2eKvhN1Z6MNkLXjQV[jhiUE
xZF9abtZuU1kKFNsC5cumJxJmVnN11mQng3aV93d0z RX9wX1VYXz6Dgcn6epR6jz
xZs6S0s3jFkTvNMVYU02z2dH2mipOHEWm9n931ZV1EZT02vm1FWD0c2vQXVakvPZVOYm
xSBZ9s22dDBWFieE4s4dYiUVmNszzGV7gRoUgyec2bl3IPuqjQTVFVZVQy1jR2mt5CNQ
UX10cGmYQyatUDE1CTEJZ1Vw6c3h13RERVz2A5mtWGT5Z2cERtI5Hdpcc00E0DDNVW5j
S5WVdqRUTqFQko2T01NNuMhN24cDMV1uUTdFTXew23F2VDR10jUSJnFwFjA3TtC7lUpPe
em0cOzh3yU3sD3aqFZU3V2RJRCCxJxXaT2aULR1boVa2lX1cVS1CSSNnWkXGNg1tb0OjTj
NSXzshnRNWYW2G51a3Z6U9GLYmpJry10UEU2R11X3pHaFVFLFBV114LeVMKZMD6dJR1W10
bdkrtXQrYTFG0W9hUttD0Q1Vrx0hvbjdO0UwhxUl1g12HZNVM4bGsiL2HzVrFZMNDmdqXoa9wYV
kzbD1lQVFPYhVMT0ANfPFFVTvSt3tDjT1QazFVYmpaGFMGMEU3ej1j1Tn1e5FEMTWVhakz
TKWFDV11fOGOF41noQuktXN24MaNNuT0xz0VdNWNNKT1BGVTZpcwNR19o3j1n1KMNKRhbD
VtQY0ncBiJUtULhuckXrZ01ZSN2E2V2dGFbni1DUV6VURAwR3zoqZ2VlWDcQVQd3BK
NOM3xNxdYUt1LSmtTCSmtTUpODd1N3aohoWEIrcneazRHVpMDsDqFY3YsH7RThxwnDpnmXmsJ5V
EycJ1M1NWCkotVhodPcpFpY3RdPDW96LTA4AWhdQ3RkTEliSFFWTG40jrIjMRTranU0dUXs
b5Jnc043M3W113cdCVMvEZDj6R3NMD3zDGzX0V5KxW5kWRU
9nThkici1rMDY1bW0OV5lVUVyMs5ODVNSK0xZvnxIT0kdKNGVNXkxyYKtNtmcveEFVP1Bn
RnJzU0F1c2JJOw4eVjTnTWeaenYjDgC04w55j1ccXNCXeA1R8Ew2XFstI1lyMX1B1VTVF
1FzX2BampKSF13dSdvZBXRKNJF2awpqGRDOW3gU3UxJadSyoHdJxUzZsdjDEsmYNr1ht
UGQyc0mZnuZyNjMnMkFzX3bHmuneH3cnFlWavBfL3CFmpFkVtmgQyty1bN2NHxVxUl
1LWw54cHvNwVdNSjRyb1dRe1tjWTGNTUE4jV4ETenFSF2s3unRwNWXMX141VM4Nj0vC0hVz
da1ObxizyuUYR221od12FYXnRdWrrcGlyWknlNH1JUXtaahNFQj1USmdvB3dSaxyFX0F2
I5dklObzEexxizHxdmp2RnnKNNOVVU1mAeG2ER2sdSanB5nUSR1zRh1J205UVNVEE
T01UM1wOLSNRywoeWtc3dPdqXbqjzi21z0Q5E1gwec2kR1FDMTDrjdBSQ2SVSTvDf
Vbvb5hSU1wzuZRZ1jIsjk451RINmckN5bklJSWUcDbhxNhbs0A50e7oq2tMjuz3b3h2dY0
WF9Bul1mTk0a50e5W5BR0ddCcktunjWNRVxUEfMbMK1MYVpxU1J7Mzmq4GS3y2JEdk
5R5ihiQQW9B0r4VaGwUcROXFmLYvqko3cEtUyVUSbh4r4TsOVNYze2c1RimN2oaaxd
VEFBJVJaWwEn0TutODF1c12Rzk1fUIbEhHFNT9QWVKV2zyQkF6FW9uSHeKvHsaVh5SYBIO
hLeccdEFd0V0TTw0JU02mAn102z8L2z1c0WzdBR3pSBV09mz6Fsk200Q0U0ZTWHRB
QmNmd2dMLUU1cvHsCU3JNEhvt5q51GIDjVFMUnlCj0Yn1oi1kxbEeEwZvJW1VNSjU1Re
ExOEgyFBFR1eEXbkh19HZETSdrznm2NMDJUCndsYzW1n19fQ,
"protected": "kWGFN2s2-KnTrigjsXusZ1nU1nKnaX0",
"RSAwithSHA25A"

header: {
  "kid": "e9bc097a-ce51-4036-9562-2dade882db0d",
  "signer": {
    "MIIC3cCAkcAgwIBAgIyJAf2FEKEyeMoA0GCSqGSIb3DQEDBQUAMFOcCwCzAeBqwBA
    YTA1VTMCMTrMQWQDVPQADpYpxmZ9ybmlMrMWREQyDQHPdAPyWzxm9ybmllmHSEw
    HvYDQVQKBhJeBnR1c5sldmCDBxvWArnXrzF0B0eSMMdQGWhcNMTUWxZnYMDkME4W
    hcNMjAwNjMwDkWME4rjBaMqWsQCYDVoQEGwJuVUE7MBGAE1UECaKQ2FsaWz2vcmp3
  }

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A.1.2.2. Sample CreateSDResponse

```
{  "CreateSDTBSResponse": {   "ver": "1.0",  "status": "pass",  "rid": "req-01",  "tid": "tran-01",  "content": {   "did": "zAHkb0-SQh9U_OT8mR5dB-tygcqpoUJ9_x07pIiw8WoM",    "sdname": "sd.bank.com",    "teespaik": "AQABjY9KiwH3hkMmSAAN6CLXot525U85WN1WAQzQ5ToWCM8h-X6_EHX1OxoyRxBiKMqWb0Y2LCABTwlytIy2kWa525imRho8Vq6hDQsJGDZPDr9GnZR8pZX5ge_dWXB_uljMvDttc5iaWEJ8ZgcplGtBTGLZnQoQbjwtl11E",  } },  "signature": "nuQoQCTEBLeaRzuw7qliPIYEJ2eJfurO5sT5Y-N03zFRcvljjvqM0Htx_pw_iwY9WjmpoWfpfelhweKcc9SgbeBznzmkZbp7kjs6MmX4CKz90Apej-V7yL9Yp0WNdRh3425YeufacpCy3lcXPIn5JBAUn8OzUg3RWxcU_yGnPsw"}  
```

Below is the response message after the content is encrypted and encoded.

```
{  "CreateSDResponse": {  "payload": "eyJdcmVhdGVTRFRCU1Jlc3BvbnN1Ijp7InZlciI6IjEuMCIsInN0YXR1cyI6InBhc3MiLCJJeWJsaWQjIjoiMDEiLCJ0cmFuZ3plbWF0IjoiMjIwMjAtMDA4LTQwMDo0MDMtMTE5LTIyZDItMTM5LzYyNjQzNzQ2MThjMjUzIiwicmV0dXJuZHJhZ2U9IjIwMjgtMDQxLTQ5NjMtNTk3LTQyZmItMDQwOTM0Zjg0OTQ0ZiJ9.LRaju9oWvTwe-Jw2b-WL5w=",  }  
```
A.1.3. Sample UpdateSD

A.1.3.1. Sample UpdateSDRequest

{
  "UpdateSDTBSRequest": {
    "ver": "1.0",
    "rid": "1222DA7D-8993-41A4-AC02-8A2807B31A3A",
    "tid": "4F454A7F-002D-4157-884E-B0DD1A06A8AE",
    "tee": "Primary TEE ABC",
    "nextdsi": "false",
    "dsihash": "IsOvwpzDk8Ow4bCrsKJyVTw4vCu80Aw4JEv6zGcsK8w4JCacKxW8Kfw5o7",
    "content": {
      "tamid": "id1.TAMxyz.com",
      "spid": "com.acmebank.spid1",
      "sdname": "com.acmebank.sdname1",
      "changes": {
        "newsdname": "com.acmebank.sdname2",
        "newspid": "com.acquirer.spid1",
        "spcert": "MIIDFjCCAn-gAwIBAgIJAIAk0Tat0tquDMA0GCSqGSIb3DQEBBQUAMGwxCzAJBgNVBAgTAT5vLydIAwIwDQYJKoZIhvcNAQEFBQADgYEAMEB5dNEBnA4hTeOOG1hZ2UuY3R0ZWQgMjAwM2YxMjMwMjA5OTk4MDE1MDA4MDAwMC0xMDEwMDc2NjUyMzI3MjA3MmNkZTBiYzYwZjY1ZjNiZTg1NjE4NzFkMzVhM2FjNjIzOTY0OTBiYzY1N2E2ZTBiMzBlMjM5YmI\n"}
  }
}
A.1.3.2. Sample UpdateSDResponse

```
{ "UpdateSDTBSResponse": {  
  "ver": "1.0",
  "status": "pass",
  "rid": "1222DA7D-8993-41A4-AC02-8A2807B31A3A",
  "tid": "4F454A7F-002D-4157-884E-B0DD1A06A8AE",
  "content": {
    "did": "MTZENTE5Qzc0Qzk0NkUxMzYxNzk0NjY4NTc3OTY4NTI=",
    "teespaik": "AQABjY9KiwH3hkMmSAAN6CLXot525U85WNlWKAQz5TOdfe_CM8h-X6_EHX1gOxoyRXaBkMqWb0YYLCABTw1yt6y2kWa525imRho8Vqn6HDGvJDZPDru9GnZRs8pZX5ge_dWXB_uljMvDttc5iAWEJ8ZgcpLGtBTGLZnQoQbjwtl11IE",
    "teespaiktype": "RSA"
  }
}
```

A.1.4. Sample DeleteSD

A.1.4.1. Sample DeleteSDRequest

The TAM builds message - including data to be encrypted.

```
{ "DeleteSDTBSRequest": {  
  "ver": "1.0",
  "rid": "{712551F5-DFB3-43f0-9A63-663440B91D49}"
  "tid": "{4F454A7F-002D-4157-884E-B0DD1A06A8AE}"
  "tee": "Primary TEE",
  "nextdsi": "false",
  "dsihash": "AAECAwQFBgcICQoLDA0ODwABAgMEBQYHCAkKCwwNDg8=",
  "content": ENCRYPTED {  
    "tamid": "TAM1.com",
    "sdname": "default.acmebank.com",
    "deleteta": "1"
  }
}
```

The TAM encrypts the "content".
The TAM signs the "DeleteSDTBSRequest" to form a "DeleteSDRequest"
A.1.4.2. Sample DeleteSDResponse

The TEE creates a "DeleteSDTBSResponse" to respond to the "DeleteSDRequest" message from the TAM, including data to be encrypted.

{  
  "DeleteSDTBSResponse": {  
    "ver": "1.0",
    "status": "pass",
    "rid": "{712551F5-DFB3-43f0-9A63-663440B91D49}"},
  "content": ENCRYPTED {
    "did": "MTZENTE5Qzc0Qzk0NkUxMzYxNzk0NjY4NTc3OTY4NTI="}
}

The TEE encrypts the "content" for the TAM.
"DeleteSDTBSResponse": {
  "ver": "1.0",
  "status": "pass",
  "rid": "{712551F5-DFB3-43f0-9A63-663440B91D49}",
  "tid": "{4F454A7F-002D-4157-884E-B0DD1A06A8AE}",
  "content": {
    "protected": "eyJlbmMiOiJBMTI4Q0JDLUhTMjU2In0K",
    "recipients": [
      {
        "header": {
          "alg": "RSA1_5"
        },
        "encrypted_key": "QUVTMTI4ICChDRUspIGtleSwgZW5jcnlwdGVkIHdpdGggVFNNIFJTQSBwdWJsaWMg
          a2V5LCB1c2luZyBSU0ExXzUgcGFkZGluZw"
      },
      {
        "iv": "ySGmfZ69YlcEilNr5_SGbA",
        "ciphertext": "c2FtcGxlIGRzaSBkYXRhIGVuY3J5cHRlZCB3aXRoIEFFUzEyOCBrZXkgZnJvbSByZW
          NpcGllbnRzLmVuY3J5cHRlZF9rZXk",
        "tag": "c2FtcGxlIGF1dGlhbnRpY2F0aW9uIHRhZw"
      }
    ],
    "iv": "ySGmfZ69YlcEilNr5_SGbA",
    "ciphertext": "c2FtcGxlIGRzaSBkYXRhIGVuY3J5cHRlZCB3aXRoIEFFUzEyOCBrZXkgZnJvbSByZW
      NpcGllbnRzLmVuY3J5cHRlZF9rZXk",
    "tag": "c2FtcGxlIGF1dGlhbnRpY2F0aW9uIHRhZw"
  }
}

The TEE signs "DeleteSDTBSResponse" to form a "DeleteSDResponse"
"DeleteSDResponse": {
    "payload": "ewoJIkRlbGV0ZVNEVEJTUmVzcG9uc2UiOiB7CgkJInZlciI6ICIxLjAlAoJCSJzdGF0dXMiOiAicGFzcyIsCgkJInJpZCI6ICJ7NzEyNTUxRjUtREZCMy00M2YwLTlBNjMtNjYzNDQwJkxRDQ5fSIsCgkJInRpZCI6ICJ7NEY0NTBRNWytMDAyRC00MC00MjItMjAtNjUtNzI1OC0wMDMxOC0xMCJ9",
    "protected": "eyJhbGciOiJSUzI1NiJ9",
    "signature": "c2FtcGxlIHNpZ25hdHVyZQ"
}

The TEE returns "DeleteSDResponse" back to the OTrP Broker, which returns the message back to the TAM.

A.2. Sample TA Management Messages

A.2.1. Sample InstallTA

A.2.1.1. Sample InstallTAResult


A.2.1.2. Sample InstallTAResponse

A sample to-be-signed response of InstallTA looks as follows.

```json
{
  "InstallTATBSResponse": {
    "ver": "1.0",
    "status": "pass",
    "rid": "24BE8059-0AED-42A6-A381-817DFB7A1207",
    "tid": "4F454A7F-002D-4157-884E-B0DD1A06A8AE",
    "content": {
      "did": "MTZENTES5Qz0z30NkUxMzYxNzk0NjY4NTc3OTY4NTI",
      "dsi": {
        "tfwdata": {
          //...
```

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"tbs": "ezRGNDU0QTdGLAwMkQtNDE1Ny04ODRFLUIwREQxQTA2QThBRX0=",
"cert": "ZXhhbXBsb2dQcT0xMjQ1XjEwMTQ2",
"sigalg": "U1MyNTY=",
"sig": "c2FtcGxlIEZXIHNpZ25hdHVyZQ=="
},
"tee": {
  "name": "Primary TEE",
  "ver": "1.0",
  "cert": "c2FtcGxlIEZXIHNpZ25hdHVyZQ==",
  "cacert": [
    "c2FtcGxlIEZXIHNpZ25hdHVyZQ==",
    "c2FtcGxlIEZXIHNpZ25hdHVyZQ=="
  ],
  "sdlist": {
    "cnt": "1",
    "sd": [
      {
        "name": "com.acmebank.sdname1",
        "spid": "com.acmebank.spid1",
        "talist": [
          {
            "taid": "com.acmebank.taid.banking",
            "taname": "Acme secure banking app"
          },
          {
            "taid": "acom.acmebank.taid.loyalty.rewards",
            "taname": "Acme loyalty rewards app"
          }
        ]
      }
    ]
  },
  "teeaiklist": [
    {
      "spaik": "c2FtcGxlIEFTTjEgZW5jb2RlZCBQS0NTMSBwdWJsaWNRZXk=",
      "spaiktype": "RSA"
    },
    {
      "spaik": "c2FtcGxlIEFTTjEgZW5jb2RlZCBQS0NTMSBwdWJsaWNRZXk=",
      "spaiktype": "RSA"
    }
  ]
}
A.2.2. Sample UpdateTA

A.2.2.1. Sample UpdateTARequest

```json
{
  "UpdateTATBSRequest": {
    "ver": "1.0",
    "rid": "req-2",
    "tid": "tran-01",
    "tee": "SecuriTEE",
    "nextdsi": false,
    "dsihash": "gwjul_SMZks3pqUSN1-eL1aVwGXNAxk0AIKW79dn4U",
    "content": {
      "tamid": "TAM1.acme.com",
      "spid": "bank.com",
      "sdname": "sd.bank.com",
      "taid": "sd.bank.com.ta"
    },
    "encrypted_ta": {
      "key": "XzmAn_RDVk3IozMwWhiB6fmZlIs1YUvMK1qA_v_UDoZ1fvGGsRGo9bT0A4400sYMqLtG11KypoJcjgjdaHgamaJgRSc4Je2otpnEEagsahvDNSoarMCC5nGQdkRxW7Vo2NkgL892HGeHkJVshYm1cUIFQ-BhiJ4NAykFw1qC_oc",
      "iv": "AxY8DctDglsbGljb3RoZQ",
      "alg": "AESCBC",
      "ciphernewtadata": "KHqOxGn7ibF_14PG4_UX9DBjocWkIAzhvVE-U-67NsKryHGeWr2spRwfddU2KWaNncHoYGwEthCH7XyNbOFh28nzwUmstep4nHWba1XZYTnKENCABPpuw_G313HADO"
  }
}
```

```json
{
  "UpdateTARequest": {
    "payload": "eyJvcGRhdGVuQVVRcUl1c3VcL3QiOnsidmVyIjoiMS4wIiwicmlkIjoicmVxLTIiLCJ0aWQiOiJ0cmFuLTAxIiwidGVlIjoiU2VjdXp0dWVEFVhipb3RzIn0sInVpZCI6ImF3a2dTaWxhZHkxLWN2b2FyaSIsInN0c3R5bGVzIjoiZmF2aXJpYyI6IjI0IiwicmVzcGxlIjoidmlld01SIn0sInZlcnNpb25zIjoidmV3In0sIhm3cDVCaXNyIjoiMjAyMiJ9",
    "ciphernewtadata": "KhqOxGn7ibF_14PG4_UX9DBjocWkIAzhvVE-U-67NsKryHGeWr2spRwfddU2KWaNncHoYGwethCH7XyNbOFh28nzwUmstep4nHWba1XZYTnKENCABPpuw_G313HADO"
  }
}
```
A.2.2.2. Sample UpdateTAResponse

Pei, et al. Expires April 26, 2019 [Page 103]
{ "UpdateTATBSResponse": { "ver": "1.0", "status": "pass", "rid": "req-2", "tid": "tran-01", "content": { "did": "zAHkb0-SQh9U_OT8mR5dB-tygcqpuJ9_x07pIiw8WoM" } } }
{"UpdateTAResponse":{
  "payload":
  eyJVcGRhdGVUQVRCU1Jlc3BvbnnJi7pInZlci16IjEuMCIsInN0YXR1cyI6InBhc3Mi
  LCJyaWQiOiJyZXEtMiIsI1RzZCI6InRyYW4tMTIvIjwvMDIi
  "protected":"eyJhbGciOiJSUzI1NiJ9",
  "header": {
    "kid":"e9bc097a-ce51-4036-9562-2dade828db0d",
    "signer":
  MIIC3zCCAkigAwIBAgIIBf2fKE1BYOMA0GCSqGSIb3DQEBBQUAMIGF0cCzAJBgNVBA
  YTAlVTMRmMrwOjRQvQJoQm4xMjIwNzAyMDkwMTE4WhcNMjAwNjMwMDkwMTE4WjBQL
  "signature":
  Twajmt_BBLIMcNrDsjqr8lI7O7lEQxXZNhlUOtFkOMMqf37wOPKtp_99LoS82CVmdpCo
  UBFyfTrd5Tqj1lnqH3a_Y3Qpuc0Jg"
  },
  "signature":
  Twajmt_BBL1McNdjsq81I7O71EQQXXNh1UOtFk0MQf37wOPKtp_99LoS82CVmdpCo
  PLaws8zzh-SNIQ42-
  NiO8_9BaEGC1Wy18Yg9f9FWFNwFv2rI2f12D4uKnkYu1EMBN4YfP81n_PGpb4Gm-
  nNk14grVZywAPej3Zzk"}
}
A.2.3. Sample DeleteTA

A.2.3.1. Sample DeleteTARequest

```json
{
  "DeleteTATBSRequest": {
    "ver": "1.0",
    "rid": "req-2",
    "tid": "tran-01",
    "tee": "SecuriTEE",
    "nextdsi": "false",
    "dsihash": "gwjul_9MZks3pqUSN1-eLlaViwGXNAXk0AIKW79dn4U",
    "content": {
      "tamid": "TAM1.acme.com",
      "sdname": "sd.bank.com",
      "taid": "sd.bank.com.ta"
    }
  }
}
```
A.2.3.2. Sample DeleteTAResponse

```json
{
    "DeleteTATBSResponse": {
        "ver": "1.0",
        "status": "pass",
        "rid": "req-2",
        "tid": "tran-01",
        "content": {
            "did": "zAHkb0-SQh9U_OT8mR5dB-tygcqpuJ9_x07pIiw8WoM"
        }
    }
}
```
"DeleteTAResponse": {
"payload":
"ew0KCSJEZWxldGVUVC1ldmVuYmFyOjEwMDAwLCAKCSJjaXBoZXJ0ZXh0IjogIjEwMDAwLCAK
"protected": "eyJhbGciOiJSUzI1NiJ9",
"header": {
"kid": "e9bc097a-ce51-4036-9562-d2ade882db0d",
"signer": "MIICCzCCAkigAwIBAgIJAjg1OAwIgYDVQQIEwJXaWdpdHRoMRMwEQYDVQQK
MBEGA1UECAwKQ2FsaWZvcm5pYTEhMB8G
"signature": "DfoBOetNelKsnAe_m4Z9K5eqo9w1Ksyo08wx2hRNg
"}
}
A.3. Example OTrP Broker Option

The most popular TEE devices today are Android powered devices. In an Android device, an OTrP Broker can be a bound service with a service registration ID that a Client Application can use. This option allows a Client Application not to depend on any OTrP Broker SDK or provider.

An OTrP Broker is responsible to detect and work with more than one TEE if a device has more than one. In this version, there is only one active TEE such that an OTrP Broker only needs to handle the active TEE.

Appendix B. Contributors

- Brian Witten
  Symantec
  brian_witten@symantec.com

- Tyler Kim
  Solacia
  tylerkim@iotrust.kr

Authors’ Addresses

Mingliang Pei
Symantec
350 Ellis St
Mountain View, CA  94043
USA

Email: mingliang_pei@symantec.com

Andrew Atyeo
Intercede
St. Mary’s Road, Lutterworth
Leicestershire, LE17  4PS
Great Britain

Email: andrew.atyeo@intercede.com
Nick Cook
ARM Ltd.
110 Fulbourn Rd
Cambridge, CB1 9NJ
Great Britain

Email: nicholas.cook@arm.com

Minho Yoo
IoTrust
Suite 501, Gasanbusiness Center,165, Gasan digital1-ro
Seoul 08503
Korea

Email: minho.yoo@iotrust.kr

Hannes Tschofenig
ARM Ltd.
110 Fulbourn Rd
Cambridge, CB1 9NJ
Great Britain

Email: hannes.tschofenig@arm.com
The Open Trust Protocol (OTrP)
draft-ietf-teep-opentrustprotocol-03.txt

Abstract

This document specifies the Open Trust Protocol (OTrP), a protocol that follows the Trust Execution Environment Provisioning (TEEP) architecture and provides a message protocol that provisions and manages Trusted Applications into a device with a Trusted Execution Environment (TEE).

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

Internet-Drafts are working documents of the Internet Engineering Task Force (IETF). Note that other groups may also distribute working documents as Internet-Drafts. The list of current Internet-Drafts is at https://datatracker.ietf.org/drafts/current/.

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1. Introduction

The Trusted Execution Environment (TEE) concept has been designed to separate a regular operating system, also referred as a Rich Execution Environment (REE), from security-sensitive applications. In an TEE ecosystem, different device vendors may use different TEE implementations. Different application providers or device administrators may choose to use different TAM providers. There calls for an interoperable protocol for managing TAs running in different TEEs of various devices is needed.

The Trusted Execution Environment Provisioning (TEEP) architecture document [TEEPArch] has set to provide a design guidance for such an interoperable protocol. This document specifies an Open Trust Protocol (OTrP) that follows the architecture guidance.

OTrP defines a mutual trust message protocol between a TAM and a TEE and relies on IETF-defined end-to-end security mechanisms, namely JSON Web Encryption (JWE), JSON Web Signature (JWS), and JSON Web Key (JWK). Other message encoding methods may be supported.

This specification defines message payloads exchanged between devices and a TAM. The messages are designed in anticipation of the use of the most common transport methods such as HTTPS.

Each TA binary and configuration data can be from either of two sources:

1. A TAM supplies the signed and encrypted TA binary and any required configuration data

2. A Client Application supplies the TA binary

This specification considers the first case where TA binary and configuration data are encrypted by recipient’s public key that TAM
has to be involved. The second case will also be addressed separately.

2. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

3. Terminology

3.1. Definitions

The definitions provided below are defined as used in this document. All the terms defined in the TEEP Architecture document [TEEPArch] will be used, which are not repeated in this document.

OTrP Broker: It is the Broker as defined in the TEEP Architecture document [TEEPArch].

3.2. Abbreviations

<table>
<thead>
<tr>
<th>CA</th>
<th>Certificate Authority</th>
</tr>
</thead>
<tbody>
<tr>
<td>OTrP</td>
<td>Open Trust Protocol</td>
</tr>
<tr>
<td>REE</td>
<td>Rich Execution Environment</td>
</tr>
<tr>
<td>SD</td>
<td>Security Domain</td>
</tr>
<tr>
<td>SP</td>
<td>Service Provider</td>
</tr>
<tr>
<td>TA</td>
<td>Trusted Application</td>
</tr>
<tr>
<td>TEE</td>
<td>Trusted Execution Environment</td>
</tr>
<tr>
<td>TFW</td>
<td>Trusted Firmware</td>
</tr>
<tr>
<td>TAM</td>
<td>Trusted Application Manager</td>
</tr>
</tbody>
</table>

4. OTrP Entities and Trust Model

4.1. System Components

The same system components as defined in the TEEP Architecture document [TEEPArch] are used in OTrP, including TAM, CA, TEE, REE, and OTrP Broker (a.k.a Broker).
Secure boot (for the purposes of OTrP) is optional in enabling authenticity checking of TEEs by the TAM. A TAM provider can choose it policy whether it trusts a TEE if the underlying firmware attestation information is not included.

OTrP uses trust anchors to establish trust between TEEs and TAMs and verifies that they communicate in a trusted way when performing lifecycle management transactions.

4.2. Trust Anchors in TEE

This assumes the Trust Anchor specification defined in the TEEP Architecture document [TEEPArch].

Each TEE comes with a trust store that contains a whitelist of root CA certificates that are used to validate a TAM’s certificate. A TEE will accept a TAM to create new Security Domains and install new TAs on behalf of a SP only if the TAM’s certificate is chained to one of the root CA certificates in the TEE’s trust store.

4.3. Trust Anchors in TAM

The Trust Anchor set in a TAM consists of a list of Certificate Authority certificates that signs various device TEE certificates. A TAM decides what TEE and optionally TFW it will trust when TFW signature data is present in an attestation.

4.4. Keys and Certificate Types

OTrP leverages the following list of trust anchors and identities in generating signed and encrypted command messages that are exchanged between a device’s TEE and a TAM. With these security artifacts, OTrP Messages are able to deliver end-to-end security without relying on any transport security.
<table>
<thead>
<tr>
<th>Key Entity Name</th>
<th>Location</th>
<th>Issuer</th>
<th>Trust Implication</th>
<th>Cardinality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. TFW key pair and certificate</td>
<td>Device secure storage</td>
<td>FW CA</td>
<td>A whitelist of FW root CA trusted by TAMs</td>
<td>1 per device</td>
</tr>
<tr>
<td>2. TEE key pair and certificate</td>
<td>Device TEE</td>
<td>TEE CA under a root CA</td>
<td>A whitelist of TEE root CA trusted by TAMs</td>
<td>1 per device</td>
</tr>
<tr>
<td>3. TAM key pair and certificate</td>
<td>TAM provider</td>
<td>TAM CA under a root CA</td>
<td>A whitelist of TAM root CA embedded in TEE</td>
<td>1 or multiple can be used by a TAM</td>
</tr>
<tr>
<td>4. SP key pair and certificate</td>
<td>SP SP signer CA</td>
<td>SP signer CA</td>
<td>TAM manages SP. TA trust is delegated to TAM. TEE trusts TAM to ensure that a TA is trustworthy.</td>
<td>1 or multiple can be used by a TAM</td>
</tr>
</tbody>
</table>

Table 1: Key and Certificate Types

1. **TFW key pair and certificate**: A key pair and certificate for evidence of trustworthy firmware in a device. This key pair is optional. Some TEE may present its trusted attributes to a TAM using signed attestation with a TFW key. For example, a platform that uses a hardware based TEE can have attestation data signed by a hardware protected TFW key.

    Location: Device secure storage

    Supported Key Type: RSA and ECC

    Issuer: OEM CA

    Trust Implication: A whitelist of FW root CA trusted by TAMs

    Cardinality: One per device

2. **TEE key pair and certificate**: It is used for device attestation to a remote TAM and SP.
This key pair is burned into the device at device manufacturer. The key pair and its certificate are valid for the expected lifetime of the device.

Location: Device TEE

Supported Key Type: RSA and ECC

Issuer: A CA that chains to a TEE root CA

Trust Implication: A whitelist of TEE root CA trusted by TAMs

Cardinality: One per device

3. TAM key pair and certificate: A TAM provider acquires a certificate from a CA that a TEE trusts.

Location: TAM provider

Supported Key Type: RSA and ECC.

Supported Key Size: RSA 2048-bit, ECC P-256 and P-384. Other sizes should be anticipated in future.

Issuer: TAM CA that chains to a root CA

Trust Implication: A whitelist of TAM root CA embedded in TEE

Cardinality: One or multiple can be used by a TAM

4. SP key pair and certificate: an SP uses its own key pair and certificate to sign a TA.

Location: SP

Supported Key Type: RSA and ECC

Supported Key Size: RSA 2048-bit, ECC P-256 and P-384. Other sizes should be anticipated in future.

Issuer: an SP signer CA that chains to a root CA

Trust Implication: TAM manages SP. TA trusts an SP by validating trust against a TAM that the SP uses. A TEE trusts TAM to ensure that a TA from the TAM is trustworthy.

Cardinality: One or multiple can be used by an SP
5. Protocol Scope and Entity Relations

This document specifies messages and key properties that can establish mutual trust between a TEE and a TAM. The protocol provides specifications for the following three entities:

1. Key and certificate types required for device firmware, TEEs, TAs, SPs, and TAMS

2. Data message formats that should be exchanged between a TEE in a device and a TAM

3. An OTrP Broker in the REE that can relay messages between a Client Application and TEE

Figure 1: Protocol Scope and Entity Relationship

Figure 2: OTrP System Diagram
In the previous diagram, different Certificate Authorities can be used respectively for different types of certificates. OTrP Messages are always signed, where the signer keys is the message creator’s private key such as a FW’s private key, a TEE’s private key, or a TAM’s private key.

The main OTrP component consists of a set of standard JSON messages created by a TAM to deliver device SD and TA management commands to a device, and device attestation and response messages created by a TEE that responds to a TAM’s OTrP message.

The communication method of OTrP Messages between a TAM and TEE in a device may vary between TAM and TEE providers. A mandatory transport protocol is specified for a compliant TAM and a device TEE.

An OTrP Broker is used to bridge communication between a TAM and a TEE. The OTrP Broker doesn’t need to know the actual content of OTrP Messages except for the TEE routing information.
5.1. A Sample Device Setup Flow

Step 1: Prepare Images for Devices

1. [TEE vendor] Deliver TEE Image (CODE Binary) to device OEM
2. [CA] Deliver root CA Whitelist
3. [Soc] Deliver TFW Image

Step 2: Inject Key Pairs and Images to Devices

1. [OEM] Generate Secure Boot Key Pair (May be shared among multiple devices)
2. [OEM] Flash signed TFW Image and signed TEE Image onto devices (signed by Secure Boot Key)

Step 3: Setup attestation key pairs in devices

1. [OEM] Flash TFW Public Key and a bootloader key.
2. [TFW/TEE] Generate a unique attestation key pair and get a certificate for the device.

Step 4: Setup trust anchors in devices

1. [TFW/TEE] Store the key and certificate encrypted with the eFuse key
2. [TEE vendor or OEM] Store trusted CA certificate list into devices

5.2. Derived Keys in The Protocol

The protocol generates one key pair in run time to assist message communication and anonymous verification between a TAM and a TEE.

TEE SP Anonymous Key (AIK): one derived key pair per SP in a device

The purpose of the key pair is to sign data by a TEE without using its TEE device key for anonymous attestation to a Client Application. This key pair is generated in the first SD creation for an SP. It is deleted when all SDs are removed for a SP in a device. The public key of the key pair is given to the caller Client Application and TAM for future TEE returned data validation. The public key of this AIK is also used by a TAM to encrypt TA binary data and personalization data when it sends a TA to a device for installation.
5.3. Security Domain Hierarchy and Ownership

The primary job of a TAM is to help an SP to manage its trusted application components. A TA is typically installed in an SD. An SD is commonly created for an SP.

When an SP delegates its SD and TA management to a TAM, an SD is created on behalf of a TAM in a TEE and the owner of the SD is assigned to the TAM. An SD may be associated with an SP but the TAM has full privilege to manage the SD for the SP.

Each SD for an SP is associated with only one TAM. When an SP changes TAM, a new SP SD must be created to associate with the new TAM. The TEE will maintain a registry of TAM ID and SP SD ID mapping.

From an SD ownership perspective, the SD tree is flat and there is only one level. An SD is associated with its owner. It is up to TEE implementation how it maintains SD binding information for a TAM and different SPs under the same TAM.

It is an important decision in this protocol specification that a TEE doesn’t need to know whether a TAM is authorized to manage the SD for an SP. This authorization is implicitly triggered by an SP Client Application, which instructs what TAM it wants to use. An SD is always associated with a TAM in addition to its SP ID. A rogue TAM isn’t able to do anything on an unauthorized SP’s SD managed by another TAM.

Since a TAM may support multiple SPs, sharing the same SD name for different SPs creates a dependency in deleting an SD. An SD can be deleted only after all TAs associated with this SD is deleted. An SP cannot delete a Security Domain on its own with a TAM if a TAM decides to introduce such sharing. There are cases where multiple virtual SPs belong to the same organization, and a TAM chooses to use the same SD name for those SPs. This is totally up to the TAM implementation and out of scope of this specification.

5.4. SD Owner Identification and TAM Certificate Requirements

There is a need of cryptographically binding proof about the owner of an SD in a device. When an SD is created on behalf of a TAM, a future request from the TAM must present itself as a way that the TEE can verify it is the true owner. The certificate itself cannot reliably used as the owner because TAM may change its certificate.

To this end, each TAM will be associated with a trusted identifier defined as an attribute in the TAM certificate. This field is kept
the same when the TAM renew its certificates. A TAM CA is responsible to vet the requested TAM attribute value.

This identifier value must not collide among different TAM providers, and one TAM shouldn’t be able to claim the identifier used by another TAM provider.

The certificate extension name to carry the identifier can initially use SubjectAltName:registeredID. A dedicated new extension name may be registered later.

One common choice of the identifier value is the TAM’s service URL. A CA can verify the domain ownership of the URL with the TAM in the certificate enrollment process.

A TEE can assign this certificate attribute value as the TAM owner ID for the SDs that are created for the TAM.

An alternative way to represent an SD ownership by a TAM is to have a unique secret key upon SD creation such that only the creator TAM is able to produce a Proof-of-Possession (POP) data with the secret.

5.5. Service Provider Container

A sample Security Domain hierarchy for the TEE is shown below.

```
-------
| TEE  |
-------
```

```
-------
| SP1 SD1 |
-------
```

```
-------
| SP1 SD2 |
-------
```

```
-------
| SP2 SD1 |
-------
```

OTrP segregates SDs and TAs such that a TAM can only manage or retrieve data for SDs and TAs that it previously created for the SPs it represents.
6. OTrP Broker

A TEE and TAs that run inside the TEE don’t generally have capability to communicate to the outside of the hosting device, for example, the TEE specified by Global Platform groups [GPTEE]. This calls for a software module in the REE world to handle the network communication. Each Client Application in REE may carry this communication functionality but it must also interact with the TEE for the message exchange. The TEE interaction will vary according to different TEEs. In order for a Client Application to transparently support different TEEs, it is imperative to have a common interface for a Client Application to invoke for exchanging messages with TEEs.

A shared OTrP Broker comes to meed this need. An OTrP Broker is a Rich Application or SDK that facilitates communication between a TAM and TEE. It also provides interfaces for TAM SDK or Client Applications to query and trigger TA installation that the application needs to use.

This interface for Client Applications may be commonly an Android service call for an Android powered device. A Client Application interacts with a TAM, and turns around to pass messages received from TAM to OTrP Broker.

In all cases, a Client Application needs to be able to identify an OTrP Broker that it can use.

6.1. Role of OTrP Broker

An OTrP Broker abstracts the message exchanges with the TEE in a device. The input data is originated from a TAM that a Client Application connects. A Client Application may also directly call OTrP Broker for some TA query functions.

OTrP Broker may internally process a request from TAM. At least, it needs to know where to route a message, e.g. TEE instance. It doesn’t need to process or verify message content.

OTrP Broker returns TEE / TFW generated response messages to the caller. OTrP Broker isn’t expected to handle any network connection with an application or TAM.

OTrP Broker only needs to return an OTrP Broker error message if the TEE is not reachable for some reason. Other errors are represented as response messages returned from the TEE which will then be passed to the TAM.
6.2. OTrP Broker and Global Platform TEE Client API

A Client Application may use Global Platform (GP) TEE API for TA communication. OTrP may use the GP TEE Client API but it is internal to OTrP implementation that converts given messages from TAM. More details can be found at [GPTEECLAPI].

6.3. OTrP Broker Implementation Consideration

A Provider should consider methods of distribution, scope and concurrency on device and runtime options when implementing an OTrP Broker. Several non-exhaustive options are discussed below. Providers are encouraged to take advantage of the latest communication and platform capabilities to offer the best user experience.

6.3.1. OTrP Broker Distribution

OTrP Broker installation is commonly carried out at OEM time. A user can dynamically download and install an OTrP Broker on-demand.

It is important to ensure a legitimate OTrP Broker is installed and used. If an OTrP Broker is compromised it may send rogue messages to TAM and TEE and introduce additional risks.

6.3.2. Number of OTrP Broker

We anticipate only one shared OTrP Broker instance in a device. The device’s TEE vendor will most probably supply one OTrP Broker. Potentially we expect some open source.

With one shared OTrP Broker, the OTrP Broker provider is responsible to allow multiple TAMs and TEE providers to achieve interoperability. With a standard OTrP Broker interface, TAM can implement its own SDK for its SP Client Applications to work with this OTrP Broker.

Multiple independent OTrP Broker providers can be used as long as they have standard interface to a Client Application or TAM SDK. Only one OTrP Broker is expected in a device.

TAM providers are generally expected to provide SDK for SP applications to interact with an OTrP Broker for the TAM and TEE interaction.
6.4. OTrP Broker Interfaces for Client Applications

A Client Application shall be responsible for relaying messages between the OTrP Broker and the TAM.

If a failure occurs during calling OTrP Broker, an error message described in "Common Errors" section (see Section 7.6) will be returned.

6.4.1. ProcessOTrPMessage call

Description

A Client Application will use this method of the OTrP Broker in a device to pass OTrP messages from a TAM. The method is responsible for interacting with the TEE and for forwarding the input message to the TEE. It also returns TEE generated response message back to the Client Application.

Inputs:

TAMInMsg - OTrP message generated in a TAM that is passed to this method from a Client Application.

Outputs:

A TEE-generated OTrP response message (which may be a successful response or be a response message containing an error raised within the TEE) for the client application to forward to the TAM. In the event of the OTrP Broker not being able to communicate with the TEE, a OTrPBrokerException shall be thrown.

6.4.2. GetTAInformation call

Description

A Client Application may quickly query local TEE about a previously installed TA without requiring TAM each time if it has had the TA’s identifier and previously saved TEE SP AIK public key for TA information integrity verification.

Inputs:
{ "TAQuery": { "spid": "<SP identifier value of the TA>" , "taid": "<The identifier value of the TA>" } }

Outputs:

The OTrP Broker is expected to return TA signer and TAM signer certificate along with other metadata information about the TA associated with the given identifier. It follows the underlying TEE trust model for authoring the local TA query from a Client Application.

The output is a JSON message that is generated by the TEE. It contains the following information:

*  tamid
*  SP ID
*  TA signer certificate
*  TAM certificate

The message is signed with TEE SP AIK private key.

The Client Application is expected to consume the response as follows.

The Client Application gets signed TA metadata, in particular, the TA signer certificate. It is able to verify that the result is from device by checking signer against TEE SP AIK public key it gets in some earlier interaction with TAM.

If this is a new Client Application in the device that hasn’t had TEE SP AIK public key for the response verification, the application can contact the TAM first to do GetDeviceState, and TAM will return TEE SP AIK public key to the app for this operation to proceed.

Output Message:
"TAINformationTBS": {
    "taid": "<TA Identifier from the input>",
    "tamid": "<TAM ID for the Security Domain where this TA resides>",
    "spid": "<The service provider identifier of this TA>",
    "signercert": "<The BASE64 encoded certificate data of the TA binary application’s signer certificate>",
    "signercacerts": [ < The full list of CA certificate chain including the root CA>
    ],
    "cacert": "<The BASE64 encoded CA certificate data of the TA binary application’s signer certificate>",
    "tamcert": "<The BASE64 encoded certificate data of the TAM that manages this TA>".
    "tamcacerts": [ < The full list of CA certificate chain including the root CA>
    ],
    "cacert": "<The BASE64 encoded CA certificate data of the TAM that manages this TA>",
}
}

"TAINformation": {
    "payload": "<The BASE64URL encoding of the TAINformationTBS JSON above>",
    "protected": "<BASE64URL encoded signing algorithm>",
    "header": {
        "signer": {"<JWK definition of the TEE SP AIK public key>"}
    },
    "signature": "<signature contents signed by TEE SP AIK private key BASE64URL encoded>"
}
}

where the definitions of BASE64 and BASE64URL refer to [RFC4648].

A sample JWK public key representation refers to an example in [RFC7517].
6.5. Sample End-to-End Client Application Flow

6.5.1. Case 1: A New Client Application Uses a TA

1. During the Client Application installation time, the Client Application calls TAM to initialize the device preparation step.

   A. The Client Application knows it wants to use a Trusted Application TA1 but the application doesn’t know whether TA1 has been installed or not. It can use GP TEE Client API [GPTEECLAPI] to check the existence of TA1 first. If it detects that TA1 doesn’t exist, it will contact TAM to initiate the installation of TA1. Note that TA1 could have been previously installed by other Client Applications from the same service provider in the device.

   B. The Client Application sends the TAM the TA list that it depends on. The TAM will query a device for the Security Domains and TAs that have been installed, and instructs the device to install any dependent TAs that have not been installed.

   C. In general, the TAM has the latest TA list and their status in a device because all operations are instructed by TAM. TAM has such visibility because all Security Domain deletion and TA deletion are managed by the TAM; the TAM could have stored the state when a TA is installed, updated and deleted. There is also the possibility that an update command is carried out inside TEE but a response is never received in TAM. There is also possibility that some manual local reset is done in a device that the TAM isn’t aware of the changes.

2. The TAM generates message: GetDeviceStateRequest

3. The Client Application passes the JSON message GetDeviceStateRequest to OTrP Broker call ProcessOTrPMessage. The communication between a Client Application and an OTrP Broker is up to the implementation of the OTrP Broker.

4. The OTrP Broker routes the message to the active TEE. Multiple TEE case: it is up to OTrP Broker to figure this out. This specification limits the support to only one active TEE, which is the typical case today.

5. The target active TEE processes the received OTrP message, and returns a JSON message GetDeviceStateResponse.
6. The OTrP Broker passes the GetDeviceStateResponse to the Client Application.

7. The Client Application sends GetDeviceStateResponse to the TAM.

8. The TAM processes the GetDeviceStateResponse.
   A. Extract TEEspaik for the SP, signs TEEspaik with TAM signer key
   B. Examine SD list and TA list

9. The TAM continues to carry out other actions based on the need. The next call could be instructing the device to install a dependent TA.
   A. Assume a dependent TA isn’t in the device yet, the TAM may do the following: (1) create an SD in which to install the TA by sending a CreateSDRequest message. The message is sent back to the Client Application, and then the OTrP Broker and TEE to process; (2) install a TA with an InstallTAResquest message.
   B. If a Client Application depends on multiple TAs, the Client Application should expect multiple round trips of the TA installation message exchanges.

10. At the last TAM and TEE operation, the TAM returns the signed TEE SP AIK public key to the application.

11. The Client Application stores the TEEspaik for future loaded TA trust check.

12. If the TAM finds that this is a fresh device that does not have any SD for the SP yet, then the TAM may next create an SD for the SP.

13. During Client Application installation, the application checks whether required Trusted Applications are already installed, which may have been provided by the TEE. If needed, it will contact its TAM service to determine whether the device is ready or install TA list that this application needs.

6.5.2. Case 2: A Previously Installed Client Application Calls a TA

1. The Client Application checks the device readiness: (a) whether it has a TEE; (b) whether it has TA that it depends. It may happen that TAM has removed the TA this application depends on.
2. The Client Application calls the OTrP Broker to query the TA.

3. The OTrP Broker queries the TEE to get TA information. If the given TA doesn’t exist, an error is returned.

4. The Client Application parses the TAInformation message.

5. If the TA doesn’t exist, the Client Application calls its TAM to install the TA. If the TA exists, the Client Application proceeds to call the TA.

7. OTrP Messages

The main OTrP component is the set of standard JSON messages created by a TAM to deliver device SD and TA management commands to a device, and device attestation and response messages created by TEE to respond to TAM OTrP Messages.

An OTrP Message is designed to provide end-to-end security. It is always signed by its creator. In addition, an OTrP Message is typically encrypted such that only the targeted device TEE or TAM is able to decrypt and view the actual content.

7.1. Message Format

OTrP Messages use the JSON format for JSON’s simple readability and moderate data size in comparison with alternative TLV and XML formats. More compact CBOR format may be used as an alternative choice.

JSON Message security has developed JSON Web Signing and JSON Web Encryption standard in the IETF Workgroup JOSE, see JWS [RFC7515] and JWE [RFC7516]. The OTrP Messages in this protocol will leverage the basic JWS and JWE to handle JSON signing and encryption.

7.2. Message Naming Convention

For each TAM command "xyz"", OTrP use the following naming convention to represent its raw message content and complete request and response messages:
| Purpose               | Message Name   | Example             |
|-----------------------|----------------+---------------------|
| Request to be signed  | xyzTBSRequest  | CreateSDTBSRequest  |
| Request message       | xyzRequest     | CreateSDRequest     |
| Response to be signed | xyzTBSResponse | CreateSDTBSResponse |
| Response message      | xyzResponse    | CreateSDResponse    |

7.3. Request and Response Message Template

An OTrP Request message uses the following format:

```json
{
  "<name>TBSRequest": {
    <request message content>
  }
}
```

A corresponding OTrP Response message will be as follows.

```json
{
  "<name>TBSResponse": {
    <response message content>
  }
}
```

7.4. Signed Request and Response Message Structure

A signed request message will generally include only one signature, and uses the flattened JWS JSON Serialization Syntax, see Section 7.2.2 in [RFC7515].

A general JWS object looks like the following.

```json
{
  "payload": "<payload contents>",
  "protected": "<integrity-protected header contents>",
  "header": {
    <non-integrity-protected header contents>,
  },
  "signature": "<signature contents>"
}
```
OTrP signed messages only require the signing algorithm as the mandate header in the property "protected". The "non-integrity-protected header contents" is optional.

OTrP signed message will be given an explicit Request or Response property name. In other words, a signed Request or Response uses the following template.

A general JWS object looks like the following.

```json
{
   "<name>[Request | Response]": {
      <JWS Message of <name>TBS[Request | Response]
   }
}
```

With the standard JWS message format, a signed OTrP Message looks like the following.

```json
{
   "<name>[Request | Response]": {
      "payload": "<payload contents of <name>TBS[Request | Response]>",
      "protected": "<integrity-protected header contents>",
      "header": <non-integrity-protected header contents>,
      "signature": "<signature contents>"
   }
}
```

The top element "<name>[Signed][Request|Response]" cannot be fully trusted to match the content because it doesn’t participate in the signature generation. However, a recipient can always match it with the value associated with the property "payload". It purely serves to provide a quick reference for reading and method invocation.

Furthermore, most properties in an unsigned OTrP messages are encrypted to provide end-to-end confidentiality. The only OTrP message that isn’t encrypted is the initial device query message that asks for the device state information.

Thus a typical OTrP Message consists of an encrypted and then signed JSON message. Some transaction data such as transaction ID and TEE information may need to be exposed to the OTrP Broker for routing purpose. Such information is excluded from JSON encryption. The device's signer certificate itself is encrypted. The overall final message is a standard signed JSON message.

As required by JWS/JWE, those JWE and JWS related elements will be BASE64URL encoded. Other binary data elements specific to the OTrP
7.4.1. Identifying Signing and Encryption Keys for JWS/JWE Messaging

JWS and JWE messaging allow various options for identifying the signing and encryption keys, for example, it allows optional elements including "x5c", "x5t" and "kid" in the header to cover various possibilities.

To protect privacy, it is important that the device’s certificate is released only to a trusted TAM, and that it is encrypted. The TAM will need to know the device certificate, but untrusted parties must not be able to get the device certificate. All OTrP messaging conversations between a TAM and device begin with GetDeviceStateRequest / GetDeviceStateResponse. These messages have elements built into them to exchange signing certificates, described in the section Section 9. Any subsequent messages in the conversation that follow on from this implicitly use the same certificates for signing/encryption, and as a result the certificates or references may be omitted in those subsequent messages.

In other words, the signing key identifier in the use of JWS and JWE here may be absent in the subsequent messages after the initial GetDeviceState query.

This has an implication on the TEE and TAM implementation: they have to cache the signer certificates for the subsequent message signature validation in the session. It may be easier for a TAM service to cache transaction session information but not so for a TEE in a device. A TAM can get a device’s capability by checking the response message from a TEE to decide whether it should include its TAM signer certificate and OCSP data in each subsequent request message. The device’s caching capability is reported in GetDeviceStateResponse signerreq parameter.

7.5. JSON Signing and Encryption Algorithms

The OTrP JSON signing algorithm shall use SHA256 or a stronger hash method with respective key type. JSON Web Algorithm RS256 or ES256 [RFC7518] SHALL be used for RSA with SHA256 and ECDSA with SHA256. If RSA with SHA256 is used, the JSON web algorithm representation is as follows.

"alg":"RS256"
The (BASE64URL encoded) "protected" header property in a signed message looks like the following:

"protected": "eyJhbGciOiJSUzI1NiJ9"

If ECSDA with P-256 curve and SHA256 are used for signing, the JSON signing algorithm representation is as follows.

{"alg":"ES256"}

The value for the "protected" field will be the following.

eyJhbGciOiJFUzI1NiI6I

Thus, a common OTrP signed message with ES256 looks like the following.

{
  "payload": "<payload contents>",
  "protected": "eyJhbGciOiJFUzI1NiI6I",
  "signature": "<signature contents>"
}

The OTrP JSON message encryption algorithm SHOULD use one of the supported algorithms defined in the later chapter of this document. JSON encryption uses a symmetric key as its "Content Encryption Key (CEK)". This CEK is encrypted or wrapped by a recipient’s key. The OTrP recipient typically has an asymmetric key pair. Therefore, the CEK will be encrypted by the recipient’s public key.

A compliant implementation shall support the following symmetric encryption algorithm and anticipate future new algorithms.

{"enc":"A128CBC-HS256"}

This algorithm represents encryption with AES 128 in CBC mode with HMAC SHA 256 for integrity. The value of the property "protected" in a JWE message will be

eyJlbmMiOiJBMTI4Q0JDLUhTMjU2In0

An encrypted JSON message looks like the following.

```json
{
    "protected": "eyJlbmMiOiJBMTI4Q0JDLUhTMjU2In0",
    "recipients": [
        {
            "header": {
                "alg": "<RSA1_5 etc.>",
            },
            "encrypted_key": "<encrypted value of CEK>"
        }
    ],
    "iv": "<BASE64URL encoded IV data>",
    "ciphertext": "<Encrypted data over the JSON plaintext (BASE64URL)>",
    "tag": "<JWE authentication tag (BASE64URL)>"
}
```

OTrP doesn’t use JWE AAD (Additional Authenticated Data) because each message is always signed after the message is encrypted.

7.5.1. Supported JSON Signing Algorithms

The following JSON signature algorithm is mandatory support in the TEE and TAM:

- RS256

ES256 is optional to support.

7.5.2. Support JSON Encryption Algorithms

The following JSON authenticated encryption algorithm is mandatory support in TEE and TAM.

- A128CBC-HS256

A256CBC-HS512 is optional to support.

7.5.3. Supported JSON Key Management Algorithms

The following JSON key management algorithm is mandatory support in TEE and TAM.

- RSA1_5

ECDH-ES+A128KW and ECDH-ES+A256KW are optional to support.
7.6. Common Errors

An OTrP Response message typically needs to report the operation status and error causes if an operation fails. The following JSON message elements should be used across all OTrP Messages.

"status": "pass | fail"

"reason": {
  "error-code": "<error code if there is any>",
  "error-message": "<error message>"
}

"ver": "<version string>"

7.7. OTrP Message List

The following table lists the OTrP commands and therefore corresponding Request and Response messages defined in this specification. Additional messages may be added in the future when new task messages are needed.

**GetDeviceState**
- A TAM queries a device’s current state with a message GetDeviceStateRequest. A device TEE will report its version, its FW version, and list of all SDs and TAs in the device that is managed by the requesting TAM. TAM may determine whether the device is trustworthy and decide to carry out additional commands according to the response from this query.

**CreateSD**
- A TAM instructs a device TEE to create an SD for an SP. The recipient TEE will check whether the requesting TAM is trustworthy.

**UpdateSD**
- A TAM instructs a device TEE to update an existing SD. A typical update need comes from SP certificate change, TAM certificate change and so on. The recipient TEE will verify whether the TAM is trustworthy and owns the SD.

**DeleteSD**
- A TAM instructs a device TEE to delete an existing SD. A TEE conditionally deletes TAs loaded in the SD according to a request parameter. An SD cannot be deleted until all TAs in this SD are deleted. If this is the last SD for an SP, TEE MAY also delete TEE SP AIK key for this SP.
InstallTA -
A TAM instructs a device to install a TA into an SD for an SP. The TEE in a device will check whether the TAM and TA are trustworthy.

UpdateTA -
A TAM instructs a device to update a TA into an SD for an SP. The change may commonly be bug fix for a previously installed TA.

DeleteTA -
A TAM instructs a device to delete a TA. The TEE in a device will check whether the TAM and TA are trustworthy.

7.8. OTrP Request Message Routing Rules

For each command that a TAM wants to send to a device, the TAM generates a request message. This is typically triggered by a Client Application that uses the TAM. The Client Application initiates contact with the TAM and receives TAM OTrP Request messages according to the TAM’s implementation. The Client Application forwards the OTrP message to an OTrP Broker in the device, which in turn sends the message to the active TEE in the device.

The current version of this specification assumes that each device has only one active TEE, and the OTrP Broker is responsible to connect to the active TEE. This is the case today with devices in the market.

When the TEE responds to a request, the OTrP Broker gets the OTrP response messages back to the Client Application that sent the request. In case the target TEE fails to respond to the request, the OTrP Broker will be responsible to generate an error message to reply the Client Application. The Client Application forwards any data it received to its TAM.

7.8.1. SP Anonymous Attestation Key (SP AIK)

When the first new Security Domain is created in a TEE for an SP, a new key pair is generated and associated with this SP. This key pair is used for future device attestation to the service provider instead of using the device’s TEE key pair.

8. Transport Protocol Support

The OTrP message exchange between a TEE device and TAM generally takes place between a Client Application in REE and TAM. A device that is capable to run a TEE and PKI based cryptographic attestation
isn’t generally resource constraint to carry out standard HTTPS connections. A compliant device and TAM SHOULD support HTTPs.

9. Detailed Messages Specification

For each message in the following sections all JSON elements are mandatory if not explicitly indicated as optional.

9.1. GetDeviceState

This is the first command that a TAM will send to a device. This command is triggered when an SP’s Client Application contacts its TAM to check whether the underlying device is ready for TA operations.

This command queries a device’s current TEE state. A device TEE will report its version, its FW version, and list of all SDs and TAs in the device that is managed by the requesting TAM. TAM may determine whether the device is trustworthy and decide to carry out additional commands according to the response from this query.

The request message of this command is signed by the TAM. The response message from the TEE is encrypted. A random message encryption key (MK) is generated by TEE, and this encrypted key is encrypted by the TAM’s public key such that only the TAM that sent the request is able to decrypt and view the response message.

9.1.1. GetDeviceStateRequest message

```
{
  "GetDeviceStateTBSRequest": {
    "ver": "1.0",
    "rid": "<Unique request ID>",
    "tid": "<transaction ID>",
    "ocspdat": ["<a list of OCSP stapling data>"]
    "supportedsigalgs": ["<array of supported signing algorithms>"]
}
```

The request message consists of the following data elements:

- ver - version of the message format
- rid - a unique request ID generated by the TAM
- tid - a unique transaction ID to trace request and response. This can be from a prior transaction’s tid field, and can be used in subsequent message exchanges in this TAM session. The combination of rid and tid MUST be made unique.
ocspdat - A list of OCSP stapling data respectively for the TAM certificate and each of the CA certificates up to the root certificate. The TAM provides OCSP data such that a recipient TEE can validate the TAM certificate chain revocation status without making its own external OCSP service call. A TEE MAY cache the CA OCSP data such that the array may contain only the OCSP stapling data for the TAM certificate in subsequent exchanges. This is a mandatory field.

supportedsigalgs - an optional property to list the signing algorithms that the TAM is able to support. A recipient TEE MUST choose an algorithm in this list to sign its response message if this property is present in a request. If it is absent, the TEE may use any compliant signing algorithm that is listed as mandatory support in this specification.

The final request message is JSON signed message of the above raw JSON data with TAM’s certificate.

```
{
"GetDeviceStateRequest": {
    "payload": "<BASE64URL encoding of the GetDeviceStateTBSRequest JSON above>",
    "protected": "<BASE64URL encoded signing algorithm>",
    "header": {
      "x5c": "<BASE64 encoded TAM certificate chain up to the root CA certificate>",
      "signature": "<signature contents signed by TAM private key>"
    }
}
```

The signing algorithm SHOULD use SHA256 with respective key type. The mandatory algorithm support is the RSA signing algorithm. The signer header "x5c" is used to include the TAM signer certificate up to the root CA certificate.

9.1.2. Request processing requirements at a TEE

Upon receiving a request message GetDeviceStateRequest at a TEE, the TEE MUST validate a request:

1. Validate JSON message signing. If it doesn’t pass, an error message is returned.

2. Validate that the request TAM certificate is chained to a trusted CA that the TEE embeds as its trust anchor.
* Cache the CA OCSP stapling data and certificate revocation check status for other subsequent requests.

* A TEE can use its own clock time for the OCSP stapling data validation.

3. Optionally collect Firmware signed data

* This is a capability in ARM architecture that allows a TEE to query Firmware to get FW signed data. It isn't required for all TEE implementations. When TFW signed data is absent, it is up to a TAM’s policy how it will trust a TEE.

4. Collect SD information for the SD owned by this TAM

9.1.3. Firmware Signed Data

Firmware isn’t expected to process or produce JSON data. It is expected to just sign some raw bytes of data.

The data to be signed by TFW key needs be some unique random data each time. The (UTF-8 encoded) "tid" value from the GetDeviceStateTBSRequest shall be signed by the firmware. TAM isn’t expected to parse TFW data except the signature validation and signer trust path validation.

It is possible that a TEE can get some valid TFW signed data from another device. The TEE is responsible to validate TFW integrity to ensure that the underlying device firmware is trustworthy. In some cases, a TEE isn’t able to get a TFW signed data, in which case the TEE trust validation is up to a TAM to decide. A TAM may opt to trust a TEE basing on the TEE signer and additional information about a TEE out-of-band.

When TFW signed data is available, a TAM validates the TEE and trusts that a trusted TEE has carried out appropriate trust check about a TFW.

TfwData: {
    "tbs": "<TFW to be signed data, BASE64 encoded>",
    "cert": "<BASE64 encoded TFW certificate>",
    "sigalg": "Signing method",
    "sig": "<TFW signed data, BASE64 encoded>"
}

It is expected that a FW uses standard signature methods for maximal interoperability with TAM providers. The mandatory support list of signing algorithm is RSA with SHA256.
The JSON object above is constructed by a TEE with data returned from the FW. It isn’t a standard JSON signed object. The signer information and data to be signed must be specially processed by a TAM according to the definition given here. The data to be signed is the raw data.

9.1.3.1. Supported Firmware Signature Methods

TAM providers shall support the following signature methods. A firmware provider can choose one of the methods in signature generation.

- RSA with SHA256
- ECDSA with SHA 256

The value of "sigalg" in the TfwData JSON message SHOULD use one of the following:

- RS256
- ES256

9.1.4. Post Conditions

Upon successful request validation, the TEE information is collected. There is no change in the TEE in the device.

The response message shall be encrypted where the encryption key shall be a symmetric key that is wrapped by TAM’s public key. The JSON Content Encryption Key (CEK) is used for this purpose.

9.1.5. GetDeviceStateResponse Message

The message has the following structure.

```json
{
  "GetDeviceTEEStateTBSResponse": {
    "ver": "1.0",
    "status": "pass | fail",
    "rid": "<the request ID from the request message>",
    "tid": "<the transaction ID from the request message>",
    "signerreq": true | false // about whether TAM needs to send signer data again in subsequent messages,
    "edsi": "<Encrypted JSON DSI information>"
  }
}
```
where

signerreq - true if the TAM should send its signer certificate and OCSP data again in the subsequent messages. The value may be "false" if the TEE caches the TAM’s signer certificate and OCSP status.

rid - the request ID from the request message

tid - the tid from the request message

edsi - the main data element whose value is JSON encrypted message over the following Device State Information (DSI).

The Device State Information (DSI) message consists of the following.
The encrypted JSON message looks like the following.
Assume we encrypt plaintext with AES 128 in CBC mode with HMAC SHA 256 for integrity, the encryption algorithm header is:

{"enc":"A128CBC-HS256"}

The value of the property "protected" in the above JWE message will be:

eyJlbmMiOiJBMTI4Q0JDLUhTMjU2In0

In other words, the above message looks like the following:

{
  "protected": "eyJlbmMiOiJBMTI4Q0JDLUhTMjU2In0",
  "recipients": [
    {
      "header": {
        "alg": "RSA1_5"
      },
      "encrypted_key": "<encrypted value of CEK>"
    }
  ],
  "iv": "<BASE64URL encoded IV data>",
  "ciphertext": "<Encrypted data over the JSON object of dsi (BASE64URL)>",
  "tag": "<JWE authentication tag (BASE64URL)>"
}

The full response message looks like the following:
The CEK will be encrypted by the TAM public key in the device. The TEE signed message has the following structure.

```json
{
  "GetDeviceTEEStateResponse": {
    "ver": "1.0",
    "status": "pass | fail",
    "rid": "<the request ID from the request message>",
    "tid": "<the transaction ID from the request message>",
    "signerreq": "true | false",
    "edsi": {
      "protected": "<BASE64URL encoding of encryption algorithm header JSON data>",
      "recipients": [
        {
          "header": {
            "alg": "RSA1_5"
          },
          "encrypted_key": "<encrypted value of CEK>"
        }]
      },”iv": "<BASE64URL encoded IV data>",
    "ciphertext": "<Encrypted data over the JSON object of dsi (BASE64URL)>",
    "tag": "<JWE authentication tag (BASE64URL)>"
  }
}
```

The signing algorithm shall use SHA256 with respective key type, see Section 7.5.1.

The final GetDeviceStateResponse response message consists of an array of TEE responses.
9.1.6. Error Conditions

An error may occur if a request isn’t valid or the TEE runs into some error. The list of possible error conditions is the following.

ERR_REQUEST_INVALID The TEE meets the following conditions with a request message: (1) The request from a TAM has an invalid message structure; mandatory information is absent in the message; or an undefined member or structure is included. (2) TEE fails to verify the signature of the message or fails to decrypt its contents.

ERR_UNSUPPORTED_MSG_VERSION The TEE receives a version of message that the TEE can’t deal with.

ERR_UNSUPPORTED_CRYPTO_ALG The TEE receives a request message encoded with a cryptographic algorithm that the TEE doesn’t support.

ERR_TFW_NOT_TRUSTED The TEE considers the underlying device firmware be not trustworthy.

ERR_TAM_NOT_TRUSTED The TEE needs to make sure whether the TAM is trustworthy by checking the validity of the TAM certificate and OCSP stapling data and so on. If the TEE finds the TAM is not reliable, it returns this error code.

ERR_TEE_FAIL If the TEE fails to process a request because of its internal error but is able to sign an error response message, it will return this error code.

The response message will look like the following if the TEE signing can work to sign the error response message.
{  
"GetDeviceTEEStateTBSResponse": {  
"ver": "1.0",  
"status": "fail",  
"rid": "<the request ID from the request message>",  
"tid": "<the transaction ID from the request message>",  
"reason": {"error-code": "<error code>"},  
"supportedsigalgs": [<an array of signature algorithms that the TEE supports>]  
}  
}  

where

supportedsigalgs - an optional property to list the JWS signing algorithms that the active TEE supports. When a TAM sends a signed message that the TEE isn’t able to validate, it can include signature algorithms that it is able to consume in this status report. A TAM can generate a new request message to retry the management task with a TEE-supported signing algorithm.

If the TEE isn’t able to sign an error message due to an internal device error, a general error message should be returned by the OTrP Broker.

9.1.7. TAM Processing Requirements

Upon receiving a GetDeviceStateResponse message at a TAM, the TAM MUST validate the following.

- Parse to get list of GetDeviceTEEStateResponse JSON objects
- Parse the JSON "payload" property and decrypt the JSON element "edsi". The decrypted message contains the TEE signer certificate.
- Validate the GetDeviceTEEStateResponse JSON signature. The signer certificate is extracted from the decrypted message in the last step.
- Extract TEE information and check it against its TEE acceptance policy.
- Extract the TFW signed element, and check the signer and data integration against its TFW policy.
- Check the SD list and TA list and prepare for a subsequent command such as "CreateSD" if it needs to have a new SD for an SP.
9.2. Security Domain Management

9.2.1. CreateSD

This command is typically preceded with a GetDeviceState command that has acquired the device information of the target device by the TAM. The TAM sends such a command to instruct a TEE to create a new Security Domain for an SP.

A TAM sends an OTrP CreateSDRequest Request message to a device TEE to create a Security Domain for an SP. Such a request is signed by the TAM where the TAM signer may or may not be the same as the SP’s TA signer certificate. The resulting SD is associated with two identifiers for future management:

- TAM as the owner. The owner identifier is a registered unique TAM ID that is stored in the TAM certificate.
- SP identified by its TA signer certificate as the authorization. A TAM can add more than one SP certificate to an SD.

A Trusted Application that is signed by a matching SP signer certificate for an SD is eligible to be installed into that SD. The TA installation into an SD by a subsequent InstallTARequest message may be instructed from a TAM.

9.2.1.1. CreateSDRequest Message
The request message for CreateSD has the following JSON format.

```json
{
    "CreateSDTBSRequest": {
        "ver": "1.0",
        "rid": "<unique request ID>",
        "tid": "<transaction ID>", // this may be from prior message
        "tee": "<TEE routing name from the DSI for the SD's target>",
        "nextdsi": true | false,
        "dsihash": "<hash of DSI returned in the prior query>",
        "content": ENCRYPTED { // this piece of JSON data will be
            // encrypted
            "spid": "<SP ID value>",
            "sdname": "<SD name for the domain to be created>",
            "spcert": "<BASE64 encoded SP certificate>",
            "tamid": "<An identifiable attribute of the TAM certificate>",
            "did": "<SHA256 hash of the TEE cert>"
        }
    }
}
```

In the message,

rid - A unique value to identify this request

tid - A unique value to identify this transaction. It can have the same value for the tid in the preceding GetDeviceStateRequest.

tee - TEE ID returned from the previous GetDeviceStateResponse.

nextdsi - Indicates whether the up-to-date Device State Information (DSI) is expected in the response from the TEE to this request.

dsihash - The BASE64-encoded SHA256 hash value of the DSI data returned in the prior TAM operation with this target TEE. This value is always included such that a receiving TEE can check whether the device state has changed since its last query. It helps enforce SD update order in the right sequence without accidentally overwriting an update that was done simultaneously.

content - The "content" is a JSON encrypted message that includes actual input for the SD creation. The encryption key is TAMmk that is encrypted by the target TEE’s public key. The entire message is signed by the TAM private key TAMpriv. A separate TAMmk isn’t used in the latest specification because JSON encryption will use a content encryption key for exactly the same purpose.
spid - A unique id assigned by the TAM for its SP. It should be unique within a TAM namespace.

sdname - a name unique to the SP. TAM should ensure it is unique for each SP.

spcert - The SP’s TA signer certificate is included in the request. This certificate will be stored by the device TEE which uses it to check against TA installation. Only if a TA is signed by a matching spcert associated with an SD will the TA be installed into the SD.

tamid - SD owner claim by TAM - an SD owned by a TAM will be associated with a trusted identifier defined as an attribute in the signer TAM certificate. TEE will be responsible to assign this ID to the SD. The TAM certificate attribute for this attribute tamid MUST be vetted by the TAM signer issuing CA. With this trusted identifier, the SD query at TEE can be fast upon TAM signer verification.

did - The SHA256 hash of the binary-encoded device TEE certificate. The encryption key CEK will be encrypted the recipient TEE’s public key. This hash value in the "did" property allows the recipient TEE to check whether it is the expected target to receive such a request. If this isn’t given, an OTrP message for device 2 could be sent to device 1. It is optional for the TEE to check because the successful decryption of the request message with this device’s TEE private key already proves it is the target. This explicit hash value makes the protocol not dependent on message encryption method in future.

A CreateSDTBSRequest message is signed to generate a final CreateSDRequest message as follows.

```json
{
   "CreateSDRequest": {
      "payload": "<CreateSDTBSRequest JSON above>",
      "protected": "<integrity-protected header contents>",
      "header": "<non-integrity-protected header contents>",
      "signature": "<signature contents signed by TAM private key>"
   }
}
```

The TAM signer certificate is included in the "header" property.
9.2.1.2. Request Processing Requirements at a TEE

Upon receiving a CreateSDRequest request message at a TEE, the TEE MUST do the following:

1. Validate the JSON request message as follows
   * Validate JSON message signing.
   * Validate that the request TAM certificate is chained to a trusted CA that the TEE embeds as its trust anchor.
   * Compare dsihash with its current state to make sure nothing has changed since this request was sent.
   * Decrypt to get the plaintext of the content: (a) spid, (b) sd name, (c) did.
   * Check that an SPID is supplied.
   * spcert check: check it is a valid certificate (signature and format verification only).
   * Check "did" is the SHA256 hash of its TEEcert BER raw binary data.
   * Check whether the requested SD already exists for the SP.
   * Check that the tamid in the request matches the TAM certificate’s TAM ID attribute.

2. If the request was valid, create action
   * Create an SD for the SP with the given name.
   * Assign the tamid from the TAMCert to this SD.
   * Assign the SPID and SPCert to this SD.
   * Check whether a TEE SP AIK key pair already exists for the given SP ID.
   * Create TEE SP AIK key pair if it doesn’t exist for the given SP ID.
   * Generate new DSI data if the request asks for updated DSI.

3. Construct a CreateSDResponse message
* Create raw content
  + Operation status
  + "did" or full signer certificate information,
  + TEE SP AIK public key if DSI isn’t going to be included
  + Updated DSI data if requested

* The response message is encrypted with the same JWE CEK of the request without recreating a new content encryption key.

* The encrypted message is signed with TEEpriv. The signer information ("did" or TEEcert) is encrypted.

4. Deliver the response message. (a) The OTrP Broker returns this to the Client Application; (b) The Client App passes this back to the TAM.

5. TAM processing. (a) The TAM processes the response message; (b) the TAM can look up signer certificate from the device ID "did".

If a request is illegitimate or signature doesn’t pass, a "status" property in the response will indicate the error code and cause.

9.2.1.3. CreateSDResponse Message

The response message for a CreateSDRequest contains the following content.

```
{  "CreateSDTBSResponse": {  "ver": "1.0",
         "status": "<operation result>",
         "rid": "<the request ID received>",
         "tid": "<the transaction ID received>",
         "content": ENCRYPTED {  "reason": "<failure reason detail>", // optional  "did": "<the device id received from the request>",  "sdname": "<SD name for the domain created>",  "teespaik": "<TEE SP AIK public key, BASE64 encoded>",  "dsi": "<Updated TEE state, including all SDs owned by this TAM>"  }
      }
}
```
In the response message, the following fields MUST be supplied.

**did** - The SHA256 hash of the device TEE certificate. This shows the device ID explicitly to the receiving TAM.

**teespaik** - The newly generated SP AIK public key for the given SP. This is an optional value if the device has had another domain for the SP that has triggered TEE SP AIK key pair for this specific SP.

There is a possible extreme error case where the TEE isn’t reachable or the TEE final response generation itself fails. In this case, the TAM might still receive a response from the OTrP Broker if the OTrP Broker is able to detect such error from TEE. In this case, a general error response message should be returned by the OTrP Broker, assuming OTrP Broker even doesn’t know any content and information about the request message.

In other words, the TAM should expect to receive a TEE successfully signed JSON message, a general "status" message, or none when a client experiences a network error.

```
{"CreateSDResponse": {
  "payload": "<CreateSDTBSResponse JSON above>",
  "protected": {
    "<BASE64URL of signing algorithm>"
  },
  "signature": "<signature contents signed by the TEE device private key (BASE64URL)>"
}
```

When the TEE fails to respond, the OTrP Broker will not provide a subsequent response to the TAM. The TAM should treat this as if the device has gone offline where a response is never delivered back.

**9.2.1.4. Error Conditions**

An error might occur if a request isn’t valid or the TEE runs into some error. The list of possible errors are as follows. Refer to the Error Code List (Section 13.1) for detailed causes and actions.

- ERR_REQUEST_INVALID
- ERR_UNSUPPORTED_MSG_VERSION
- ERR_UNSUPPORTED_CRYPTO_ALG
ERR_DEV_STATE_MISMATCH
ERR_SD_ALREADY_EXIST
ERR_SD_NOT_FOUND
ERR_SPCERT_INVALID
ERR_TEE_FAIL
ERR_TAM_NOT_AUTHORIZED
ERR_TAM_NOT_TRUSTED

9.2.2.  UpdateSD

This TAM initiated command can update an SP’s SD that it manages for any of the following needs: (a) Update an SP signer certificate; (b) Add an SP signer certificate when an SP uses multiple to sign TA binaries; (c) Update an SP ID.

The TAM presents the proof of the SD ownership to the TEE, and includes related information in its signed message. The entire request is also encrypted for end-to-end confidentiality.

9.2.2.1.  UpdateSDRequest Message
The UpdateSD request message has the following JSON format.

```json
{   "UpdateSDTBSRequest": {       "ver": "1.0",       "rid": "<unique request ID>",       "tid": "<transaction ID>", /* this may be from prior message       "tee": "<TEE routing name from the DSI for the SD's target>",       "nextdsi": true | false,       "dsihash": "<hash of DSI returned in the prior query>",       "content": ENCRYPTED { // this piece of JSON will be encrypted       "tamid": "<tamid associated with this SD>",       "spid": "<SP ID>",       "sdname": "<SD name for the domain to be updated>",       "changes": { // Optional       "newsdname": "<Change the SD name to this new name>",       "newspid": "<Change SP ID of the domain to this new value>",       "spcert": ["<BASE64 encoded new SP signer cert to be added>"],       "deloldspcert": ["<The SHA256 hex value of an old SP cert assigned into this SD that should be deleted >"],       "renewteespaik": true | false       }   } }
}
```

In the message,

- **rid** - A unique value to identify this request
- **tid** - A unique value to identify this transaction. It can have the same value as the tid in the preceding GetDeviceStateRequest.
- **tee** - TEE ID returned from the previous GetDeviceStateResponse
- **nextdsi** - Indicates whether the up-to-date Device State Information (DSI) is expected to be returned in the response from the TEE to this request.
- **dsihash** - The BASE64-encoded SHA256 hash value of the DSI data returned in the prior TAM operation with this target TEE. This value is always included such that a receiving TEE can check whether the device state has changed since its last query.
helps enforce SD update order in the right sequence without accidentally overwriting an update that was done simultaneously.

content - The "content" is a JSON encrypted message that includes actual input for the SD update. The standard JSON content encryption key (CEK) is used, and the CEK is encrypted by the target TEE's public key.

tamid - SD owner claim by TAM - an SD owned by a TAM will be associated with a trusted identifier defined as an attribute in the signer TAM certificate.

spid - the identifier of the SP whose SD will be updated. This value is still needed because the SD name is considered unique only within an SP.

sdname - the name of the target SD to be updated.

changes - its content consists of changes are to be updated in the given SD.

newsdname - the new name of the target SD to be assigned if this value is present.

newspid - the new SP ID of the target SD to be assigned if this value is present.

spcert - a new TA signer certificate of this SP to be added to the SD if this is present.

deloldspcert - an SP certificate assigned into the SD is to be deleted if this is present. The value is the SHA256 fingerprint of the old SP certificate.

renewteespaik - the value should be true or false. If it is present and the value is true, the TEE MUST regenerate TEE SP AIK for this SD's owner SP. The newly generated TEE SP AIK for the SP must be returned in the response message of this request. If there is more than one SD for the SP, a new SPID for one of the domains will always trigger a new teespaik generation as if a new SP were introduced to the TEE.
The UpdateSDTBSRequest message is signed to generate the final UpdateSDRequest message.

```json
{
    "UpdateSDRequest": {
        "payload": "<UpdateSDTBSRequest JSON above>",
        "protected": "<integrity-protected header contents>",
        "header": "<non-integrity-protected header contents>",
        "signature": "<signature contents signed by TAM private key>"
    }
}
```

TAM signer certificate is included in the "header" property.

9.2.2.2. Request Processing Requirements at a TEE

Upon receiving a request message UpdateSDRequest at a TEE, the TEE must validate a request:

1. Validate the JSON request message
   * Validate JSON message signing
   * Validate that the request TAM certificate is chained to a trusted CA that the TEE embeds as its trust anchor. The TAM certificate status check is generally not needed anymore in this request. The prior request should have validated the TAM certificate’s revocation status.
   * Compare dsihash with the TEE cached last response DSI data to this TAM.
   * Decrypt to get the plaintext of the content.
   * Check that the target SD name is supplied.
   * Check whether the requested SD exists.
   * Check that the TAM owns this TAM by verifying tamid in the SD matches TAM certificate’s TAM ID attribute.
   * Now the TEE is ready to carry out update listed in the "content" message.

2. If the request is valid, update action
   * If "newsdname" is given, replace the SD name for the SD to the new value
* If "newspid" is given, replace the SP ID assigned to this SD with the given new value
* If "spcert" is given, add this new SP certificate to the SD.
* If "deloldspcert" is present in the content, check previously assigned SP certificates to this SD, and delete the one that matches the given certificate hash value.
* If "renewteespaik" is given and has a value of 'true', generate a new TEE SP AIK key pair, and replace the old one with this.
* Generate new DSI data if the request asks for updated DSI
* Now the TEE is ready to construct the response message

3. Construct UpdateSDResponse message
   * Create raw content
     + Operation status
     + "did" or full signer certificate information,
     + TEE SP AIK public key if DSI isn’t going to be included
     + Updated DSI data if requested
   * The response message is encrypted with the same JWE CEK of the request without recreating a new content encryption key.
   * The encrypted message is signed with TEEpriv. The signer information ("did" or TEEcert) is encrypted.

4. Deliver response message. (a) The OTrP Broker returns this to the app; (b) The app passes this back to the TAM.

5. TAM processing. (a) The TAM processes the response message; (b) The TAM can look up the signer certificate from the device ID "did".

If a request is illegitimate or the signature doesn’t pass, a "status" property in the response will indicate the error code and cause.
9.2.2.3. UpdateSDResponse Message

The response message for a UpdateSDRequest contains the following content.

```
{
    "UpdateSDTBSResponse": {
        "ver": "1.0",
        "status": "<operation result>",
        "rid": "<the request ID received>",
        "tid": "<the transaction ID received>",
        "content": ENCRYPTED {
            "reason": "<failure reason detail>", // optional
            "did": "<the device id hash>",
            "cert": "<TEE certificate>", // optional
            "teespaik": "<TEE SP AIK public key, BASE64 encoded>",
            "teespaiktype": "<TEE SP AIK key type: RSA or ECC>",
            "dsi": "<Updated TEE state, including all SD owned by this TAM>
        }
    }
}
```

In the response message, the following fields MUST be supplied.

did – The request should have known the signer certificate of this device from a prior request. This hash value of the device TEE certificate serves as a quick identifier only. A full device certificate isn’t necessary.

teespaik – the newly generated SP AIK public key for the given SP if the TEE SP AIK for the SP is asked to be renewed in the request. This is an optional value if "dsi" is included in the response, which will contain all up-to-date TEE SP AIK key pairs.

Similar to the template for the creation of the encrypted and signed CreateSDResponse, the final UpdateSDResponse looks like the following.
When the TEE fails to respond, the OTrP Broker will not provide a subsequent response to the TAM. The TAM should treat this as if the device has gone offline where a response is never delivered back.

9.2.2.4. Error Conditions

An error may occur if a request isn’t valid or the TEE runs into some error. The list of possible errors are as follows. Refer to the Error Code List (Section 13.1) for detailed causes and actions.

ERR_REQUEST_INVALID
ERR_UNSUPPORTED_MSG_VERSION
ERR_UNSUPPORTED_CRYPTO_ALG
ERR_DEV_STATE_MISMATCH
ERR_SD_NOT_FOUND
ERR_SDNAME_ALREADY_USED
ERR_SPCERT_INVALID
ERR_TEE_FAIL
ERR_TAM_NOT_AUTHORIZED
ERR_TAM_NOT_TRUSTED

9.2.3. DeleteSD

A TAM sends a DeleteSDRequest message to a TEE to delete a specified SD that it owns. An SD can be deleted only if there is no TA associated with this SD in the device. The request message can
contain a flag to instruct the TEE to delete all related TAs in an SD and then delete the SD.

The target TEE will operate with the following logic.

1. Look up the given SD specified in the request message
2. Check that the TAM owns the SD
3. Check that the device state hasn’t changed since the last operation
4. Check whether there are TAs in this SD
5. If TA exists in an SD, check whether the request instructs whether the TA should be deleted. If the request instructs the TEE to delete TAs, delete all TAs in this SD. If the request doesn’t instruct the TEE to delete TAs, return an error "ERR_SD_NOT_EMPTY".
6. Delete the SD
7. If this is the last SD of this SP, delete the TEE SP AIK key.

9.2.3.1. DeleteSDRequest Message

The request message for DeleteSD has the following JSON format.

```
{
  "DeleteSDTBSRequest": {
    "ver": "1.0",
    "rid": "<unique request ID>",
    "tid": "<transaction ID>", // this may be from prior message
    "tee": "<TEE routing name from the DSI for the SD's target>",
    "nextdsi": true | false,
    "dsihash": "<hash of DSI returned in the prior query>",
    "content": ENCRYPTED { // this piece of JSON will be encrypted
      "tamid": "<tamid associated with this SD>",
      "sdname": "<SD name for the domain to be updated>",
      "deleteta": true | false
    }
  }
}
```

In the message,

rid - A unique value to identify this request
tid - A unique value to identify this transaction. It can have the same value for the tid in the preceding GetDeviceStateRequest.

tee - TEE ID returned from the previous response GetDeviceStateResponse

nextdsi - Indicates whether the up-to-date Device State Information (DSI) is to be returned in the response to this request.

dsihash - The BASE64-encoded SHA256 hash value of the DSI data returned in the prior TAM operation with this target TEE. This value is always included such that a receiving TEE can check whether the device state has changed since its last query. It helps enforce SD update order in the right sequence without accidentally overwriting an update that was done simultaneously.

content - The "content" is a JSON encrypted message that includes actual input for the SD update. The standard JSON content encryption key (CEK) is used, and the CEK is encrypted by the target TEE’s public key.

tamid - SD owner claim by TAM - an SD owned by a TAM will be associated with a trusted identifier defined as an attribute in the signer TAM certificate.

sdname - the name of the target SD to be updated.

deleteta - the value should be boolean 'true' or 'false'. If it is present and the value is 'true', the TEE should delete all TAs associated with the SD in the device.

According to the OTrP message template, the full request DeleteSDRequest is a signed message over the DeleteSDTBSRequest as follows.

```json
{
    "DeleteSDRequest": {
        "payload": "<DeleteSDTBSRequest JSON above>",
        "protected": "<integrity-protected header contents>",
        "header": "<non-integrity-protected header contents>",
        "signature": "<signature contents signed by TAM private key>"
    }
}
```

TAM signer certificate is included in the "header" property.
9.2.3.2. Request Processing Requirements at a TEE

Upon receiving a request message DeleteSDRequest at a TEE, the TEE must validate a request:

1. Validate the JSON request message
   * Validate JSON message signing
   * Validate that the request TAM certificate is chained to a trusted CA that the TEE embeds as its trust anchor. The TAM certificate status check is generally not needed anymore in this request. The prior request should have validated the TAM certificate’s revocation status.
   * Compare dsihash with the TEE cached last response DSI data to this TAM
   * Decrypt to get the plaintext of the content
   * Check that the target SD name is supplied
   * Check whether the requested SD exists
   * Check that the TAM owns this TAM by verifying that the tamid in the SD matches the TAM certificate’s TAM ID attribute
   * Now the TEE is ready to carry out the update listed in the "content" message

2. If the request is valid, deletion action
   * Check TA existence in this SD
   * If "deleteta" is "true", delete all TAs in this SD. If the value of "deleteta" is false and some TA exists, return an error "ERR_SD_NOT_EMPTY"
   * Delete the SD
   * Delete the TEE SP AIK key pair if this SD is the last one for the SP
   * Now the TEE is ready to construct the response message

3. Construct a DeleteSDResponse message
   * Create response content
+ Operation status
+ "did" or full signer certificate information,
+ Updated DSI data if requested

* The response message is encrypted with the same JWE CEK of the request without recreating a new content encryption key.

* The encrypted message is signed with TEEpriv. The signer information ("did" or TEEcert) is encrypted.

4. Deliver response message. (a) The OTrP Broker returns this to the app; (b) The app passes this back to the TAM

5. TAM processing. (a) The TAM processes the response message; (b) The TAM can look up signer certificate from the device ID "did".

If a request is illegitimate or the signature doesn’t pass, a "status" property in the response will indicate the error code and cause.

9.2.3.3. DeleteSDResponse Message

The response message for a DeleteSDRequest contains the following content.

```
{
  "DeleteSDTBSResponse": {
    "ver": "1.0",
    "status": "<operation result>",
    "rid": "<the request ID received>",
    "tid": "<the transaction ID received>",
    "content": ENCRYPTED {
      "reason": "<failure reason detail>", // optional
      "did": "<the device id hash>",
      "dsi": "<Updated TEE state, including all SD owned by this TAM>"
    }
  }
}
```

In the response message, the following fields MUST be supplied.

did - The request should have known the signer certificate of this device from a prior request. This hash value of the device TEE certificate serves as a quick identifier only. A full device certificate isn’t necessary.
The final DeleteSDResponse looks like the following.

```
{
   "DeleteSDResponse": {
      "payload": "<DeleteSDTBSResponse JSON above>",
      "protected": {
         "<BASE64URL of signing algorithm>"
      },
      "signature": "<signature contents signed by TEE device private key (BASE64URL)>"
   }
}
```

When the TEE fails to respond, the OTrP Broker will not provide a subsequent response to the TAM. The TAM should treat this as if the device has gone offline where a response is never delivered back.

9.2.3.4. Error Conditions

An error may occur if a request isn’t valid or the TEE runs into some error. The list of possible errors is as follows. Refer to the Error Code List (Section 13.1) for detailed causes and actions.

ERR_REQUEST_INVALID
ERR_UNSUPPORTED_MSG_VERSION
ERR_UNSUPPORTED_CRYPTO_ALG
ERR_DEV_STATE_MISMATCH
ERR_SD_NOT_EMPTY
ERR_SD_NOT_FOUND
ERR_TEE_FAIL
ERR_TAM_NOT_AUTHORIZED
ERR_TAM_NOT_TRUSTED

9.3. Trusted Application Management

This protocol doesn’t introduce a TA container concept. All TA authorization and management will be up to the TEE implementation.

The following three TA management commands are supported.
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- InstallTA - provision a TA by TAM
- UpdateTA - update a TA by TAM
- DeleteTA - remove TA registration information with an SD, remove
  the TA binary and all TA-related data in a TEE

9.3.1. InstallTA

TA binary data and related personalization data if there is any can
be from two sources:

1. A TAM supplies the signed and encrypted TA binary
2. A Client Application supplies the TA binary

This specification primarily considers the first case where a TAM
supplies a TA binary. This is to ensure that a TEE can properly
validate whether a TA is trustworthy. Further, TA personalization
data will be encrypted by the TEE device’s SP public key for end-to-
end protection. A Client Application bundled TA case will be
addressed separately later.

A TAM sends the following information in a InstallTARequest message
to a target TEE:

- The target SD information: SP ID and SD name
- Encrypted TA binary data. TA data is encrypted with the TEE SP
  AIK.
- TA metadata. It is optional to include the SP signer certificate
  for the SD to add if the SP has changed signer since the SD was
  created.

The TEE processes the command given by the TAM to install a TA into
an SP’s SD. It does the following:

- Validation
  * The TEE validates the TAM message authenticity
  * Decrypt to get request content
  * Look up the SD with the SD name
  * Checks that the TAM owns the SD
* Checks that the DSI hash matches which shows that the device state hasn’t changed

o If the request is valid, continue to do the TA validation

* Decrypt to get the TA binary data and any personalization data with the "TEE SP AIK private key"

* Check that SP ID is the one that is registered with the SP SD

* Check that the TA signer is either a newly given SP certificate or the one that is already trusted by the SD from the previous TA installation. The TA signing method is specific to a TEE. This specification doesn’t define how a TA should be signed; a TAM should support TEE specific TA signing when it supports that TEE.

* If a TA signer is given in the request, add this signer into the SD.

o If the above validation passed, continue to do TA installation

* The TEE re-encrypts the TA binary and its personalization data with its own method.

* The TEE enrolls and stores the TA in a secure storage.

o Construct a response message. This involves signing encrypted status information for the requesting TAM.

9.3.1.1. InstallTARequest Message
The request message for InstallTA has the following JSON format.

```json
{
    "InstallTATBSRequest": {
        "ver": "1.0",
        "rid": "<unique request ID>",
        "tid": "<transaction ID>",
        "tee": "<TEE routing name from the DSI for the SD’s target>",
        "nextdsi": true | false,
        "dsihash": "<hash of DSI returned in the prior query>",
        "content": ENCRYPTED {
            "tamid": "<TAM ID previously assigned to the SD>",
            "spid": "<SPID value>",
            "sdname": "<SD name for the domain to install the TA>",
            "spcert": "<BASE64 encoded SP certificate >", // optional
            "taid": "<TA identifier>",
        },
        "encrypted_ta": {
            "key": "<JWE enveloped data of a 256-bit symmetric key by the recipient’s TEEspaik public key>",
            "iv": "<hex of 16 random bytes>",
            "alg": "<encryption algoritm. AESCBC by default.>",
            "ciphertadata": "<BASE64 encoded encrypted TA binary data>",
            "cipherpdata": "<BASE64 encoded encrypted TA personalization data>
        }
    }
}
```

In the message,

- **rid** - A unique value to identify this request
- **tid** - A unique value to identify this transaction. It can have the same value for the tid in the preceding GetDeviceStateRequest.
- **tee** - TEE ID returned from the previous GetDeviceStateResponse
- **nextdsi** - Indicates whether the up-to-date Device State Information (DSI) is to be returned in the response to this request.
- **dsihash** - The BASE64-encoded SHA256 hash value of the DSI data returned in the prior TAM operation with this target TEE. This value is always included such that a receiving TEE can check whether the device state has changed since its last query. It helps enforce SD update order in the right sequence without accidentally overwriting an update that was done simultaneously.
content - The "content" is a JSON encrypted message that includes actual input for the SD update. The standard JSON content encryption key (CEK) is used, and the CEK is encrypted by the target TEE’s public key.

tamid - SD owner claim by TAM - An SD owned by a TAM will be associated with a trusted identifier defined as an attribute in the signer TAM certificate.

spid - SP identifier of the TA owner SP

sdname - the name of the target SD where the TA is to be installed

spcert - an optional field to specify the SP certificate that signed the TA. This is sent if the SP has a new certificate that hasn’t been previously registered with the target SD where the TA should be installed.

taid - the identifier of the TA application to be installed

encrypted_ta - the message portion contains encrypted TA binary data and personalization data. The TA data encryption key is placed in "key", which is encrypted by the recipient’s public key, using JWE enveloped structure. The TA data encryption uses symmetric key based encryption such as AESCBC.

According to the OTrP message template, the full request InstallTARequest is a signed message over the InstallTATBSRequest as follows.

```
{
    "InstallTARequest": {
        "payload": "<InstallTATBSRequest JSON above>",
        "protected": "<integrity-protected header contents>",
        "header": "<non-integrity-protected header contents>",
        "signature": "<signature contents signed by TAM private key>"
    }
}
```

9.3.1.2. InstallTAResponse Message

The response message for a InstallTARequest contains the following content.
{  
    "InstallTATBSResponse": {  
        "ver": "1.0",  
        "status": "<operation result>",  
        "rid": "<the request ID received>",  
        "tid": "<the transaction ID received>",  
        "content": ENCRYPTED {  
            "reason":"<failure reason detail>", // optional  
            "did": "<the device id hash>",  
            "dsi": "<Updated TEE state, including all SD owned by  
                  this TAM>"  
        }  
    }  
}  

In the response message, the following fields MUST be supplied.

did - the SHA256 hash of the device TEE certificate. This shows  
the device ID explicitly to the receiving TAM.

The final message InstallTAResponse looks like the following.

{  
    "InstallTAResponse": {  
        "payload":"<InstallTATBSResponse JSON above>",  
        "protected": {  
            "<BASE64URL of signing algorithm>"  
        },  
        "signature": "<signature contents signed by TEE device  
                     private key (BASE64URL)>"  
    }  
}  

When the TEE fails to respond, the OTrP Broker will not provide a  
subsequent response to the TAM. The TAM should treat this as if the  
device has gone offline where a response is never delivered back.

9.3.1.3. Error Conditions

An error may occur if a request isn’t valid or the TEE runs into some  
error. The list of possible errors are as follows. Refer to the  
Error Code List (Section 13.1) for detailed causes and actions.

ERR_REQUEST_INVALID

ERR_UNSUPPORTED_MSG_VERSION
9.3.2. UpdateTA

This TAM-initiated command can update a TA and its data in an SP’s SD that it manages for the following purposes.

1. Update TA binary

2. Update TA’s personalization data

The TAM presents the proof of the SD ownership to a TEE, and includes related information in its signed message. The entire request is also encrypted for end-to-end confidentiality.

The TEE processes the command from the TAM to update the TA of an SP SD. It does the following:

- **Validation**
  - The TEE validates the TAM message authenticity
  - Decrypt to get request content
  - Look up the SD with the SD name
  - Checks that the TAM owns the SD
  - Checks DSI hash matches that the device state hasn’t changed

- **TA validation**
* Both TA binary and personalization data are optional, but at least one of them shall be present in the message

* Decrypt to get the TA binary and any personalization data with the "TEE SP AIK private key"

* Check that SP ID is the one that is registered with the SP SD

* Check that the TA signer is either a newly given SP certificate or the one in SD.

* If a TA signer is given in the request, add this signer into the SD.

  o If the above validation passes, continue to do TA update

    * The TEE re-encrypts the TA binary and its personalization data with its own method

    * The TEE replaces the existing TA binary and its personalization data with the new binary and data.

  o Construct a response message. This involves signing a encrypted status information for the requesting TAM.

9.3.2.1. UpdateTARequest Message
The request message for UpdateTA has the following JSON format:

```
"UpdateTATBSRequest": {
  "ver": "1.0",
  "rid": "<unique request ID>",
  "tid": "<transaction ID>",
  "tee": "<TEE routing name from the DSI for the SD’s target>",
  "nextdsi": true | false,
  "dsihash": "<hash of DSI returned in the prior query>",
  "content": ENCRYPTED {
    "tamid": "<TAM ID previously assigned to the SD>",
    "spid": "<SPID value>",
    "sdname": "<SD name for the domain to be created>",
    "spcert": "<BASE64 encoded SP certificate>", // optional
    "taid": "<TA identifier>",
  },
  "encrypted_ta": {
    "key": "<JWE enveloped data of a 256-bit symmetric key by
            the recipient’s TEEspaik public key>",
    "iv": "<hex of 16 random bytes>",
    "alg": "<encryption algorithm. AESCBC by default.>",
    "ciphernewtadata": "<Change existing TA binary to this new TA
                      binary data(BASE64 encoded and encrypted)>",
    "ciphernewpdata": "<Change the existing data to this new TA
                      personalization data(BASE64 encoded and encrypted)>",
                      // optional
  }
}
```

In the message,

- **rid** - A unique value to identify this request
- **tid** - A unique value to identify this transaction. It can have the same value for the tid in the preceding GetDeviceStateRequest.
- **tee** - TEE ID returned from the previous GetDeviceStateResponse.
- **nextdsi** - Indicates whether the up-to-date Device State Information (DSI) is to be returned in the response to this request.
- **dsihash** - The BASE64-encoded SHA256 hash value of the DSI data returned in the prior TAM operation with this target TEE. This value is always included such that a receiving TEE can check whether the device state has changed since its last query.
helps enforce SD update order in the right sequence without accidentally overwriting an update that was done simultaneously.

content - The "content" is a JSON encrypted message that includes actual input for the SD update. The standard JSON content encryption key (CEK) is used, and the CEK is encrypted by the target TEE's public key.

tamid - SD owner claim by TAM - an SD owned by a TAM will be associated with a trusted identifier defined as an attribute in the signer TAM certificate.

spid - SP identifier of the TA owner SP

spcert - an optional field to specify the SP certificate that signed the TA. This is sent if the SP has a new certificate that hasn’t been previously registered with the target SD where the TA is to be installed.

sdname - the name of the target SD where the TA should be updated

taid - an identifier for the TA application to be updated

encrypted_ta - the message portion contains newly encrypted TA binary data and personalization data.

According to the OTrP message template, the full request UpdateTARequest is a signed message over the UpdateTATBSRequest as follows.

{  
  "UpdateTARequest": {  
    "payload": "<UpdateTATBSRequest JSON above>",  
    "protected": "<integrity-protected header contents>",  
    "header": "<non-integrity-protected header contents>",  
    "signature": "<signature contents signed by TAM private key>"  
  }  
}

9.3.2.2. UpdateTAResponse Message

The response message for a UpdateTARequest contains the following content.
In the response message, the following fields MUST be supplied.

`did` - the SHA256 hash of the device TEE certificate. This shows the device ID explicitly to the receiving TAM.

The final message `UpdateTAResponse` looks like the following.

```
{  
    "UpdateTAResponse": {  
        "payload": "<UpdateTATBSResponse JSON above>",  
        "protected": {  
            "<BASE64URL of signing algorithm>"  
        },  
        "signature": "<signature contents signed by TEE device private key (BASE64URL)>"  
    }  
}
```

When the TEE fails to respond, the OTrP Broker will not provide a subsequent response to the TAM. The TAM should treat this as if the device has gone offline where a response is never delivered back.

9.3.2.3. Error Conditions

An error may occur if a request isn’t valid or the TEE runs into some error. The list of possible errors are as follows. Refer to the Error Code List (Section 13.1) for detailed causes and actions.

ERR_REQUEST_INVALID

ERR_UNSUPPORTED_MSG_VERSION
9.3.3. DeleteTA

This operation defines OTrP messages that allow a TAM to instruct a TEE to delete a TA for an SP in a given SD. A TEE will delete a TA from an SD and also TA data in the TEE. A Client Application cannot directly access TEE or OTrP Broker to delete a TA.

9.3.3.1. DeleteTAResponse Message

The request message for DeleteTA has the following JSON format.

```json
{
  "DeleteTATBSRequest": {
    "ver": "1.0",
    "rid": "<unique request ID>",
    "tid": "<transaction ID>",
    "tee": "<TEE routing name from the DSI for the SD’s target>",
    "nextdsi": true | false,
    "dsihash": "<hash of DSI returned in the prior query>",
    "content": ENCRYPTED {
      "tamid": "<TAM ID previously assigned to the SD>",
      "sdname": "<SD name of the TA>",
      "taid": "<the identifier of the TA to be deleted from the specified SD>"
    }
  }
}
```

In the message,

```
rid - A unique value to identify this request
```

```
tid - A unique value to identify this transaction. It can have the same value for the tid in the preceding GetDeviceStateRequest.

tee - The TEE ID returned from the previous GetDeviceStateResponse

nextdsi - Indicates whether the up-to-date Device State Information (DSI) is to be returned in the response to this request.

dsihash - The BASE64-encoded SHA256 hash value of the DSI data returned in the prior TAM operation with this target TEE. This value is always included such that a receiving TEE can check whether the device state has changed since its last query. It helps enforce SD update order in the right sequence without accidentally overwriting an update that was done simultaneously.

content - The "content" is a JSON encrypted message that includes actual input for the SD update. The standard JSON content encryption key (CEK) is used, and the CEK is encrypted by the target TEE’s public key.

tamid - SD owner claim by TAM - an SD owned by a TAM will be associated with a trusted identifier defined as an attribute in the signer TAM certificate.

sdname - the name of the target SD where the TA is installed

taid - an identifier for the TA application to be deleted

According to the OTrP message template, the full request DeleteTARequest is a signed message over the DeleteTATBSRequest as follows.

```json
{
    "DeleteTARequest": {
        "payload": "<DeleteTATBSRequest JSON above>",
        "protected": "<integrity-protected header contents>",
        "header": "<non-integrity-protected header contents>",
        "signature": "<signature contents signed by TAM private key>"
    }
}
```
9.3.3.2. Request Processing Requirements at a TEE

A TEE processes a command from a TAM to delete a TA of an SP SD. It does the following:

1. Validate the JSON request message
   * The TEE validates TAM message authenticity
   * Decrypt to get request content
   * Look up the SD and the TA with the given SD name and TA ID
   * Checks that the TAM owns the SD, and TA is installed in the SD
   * Checks that the DSI hash matches and the the device state hasn’t changed

2. Deletion action
   * If all the above validation points pass, the TEE deletes the TA from the SD
   * The TEE SHOULD also delete all personalization data for the TA

3. Construct DeleteTAResponse message.

If a request is illegitimate or the signature doesn’t pass, a "status" property in the response will indicate the error code and cause.

9.3.3.3. DeleteTAResponse Message

The response message for a DeleteTAResquest contains the following content.
In the response message, the following fields MUST be supplied.

did - the SHA256 hash of the device TEE certificate. This shows the device ID explicitly to the receiving TAM.

The final message DeleteTAResponse looks like the following.

```
{
    "DeleteTAResponse": {
        "payload": "<DeleteTATBSResponse JSON above>",
        "protected": {
            "<BASE64URL of signing algorithm>"
        },
        "signature": "<signature contents signed by TEE device private key (BASE64URL)>"
    }
}
```

When the TEE fails to respond, the OTrP Broker will not provide a subsequent response to the TAM. The TAM should treat this as if the device has gone offline where a response is never delivered back.

9.3.3.4. Error Conditions

An error may occur if a request isn’t valid or the TEE runs into some error. The list of possible errors are as follows. Refer to the Error Code List (Section 13.1) for detailed causes and actions.

ERR_REQUEST_INVALID

ERR_UNSUPPORTED_MSG_VERSION
ERR_UNSUPPORTED_CRYPTO_ALG
ERR_DEV_STATE_MISMATCH
ERR_SD_NOT_FOUND
ERR_TA_NOT_FOUND
ERR_TEE_FAIL
ERR_TAM_NOT_AUTHORIZED
ERR_TAM_NOT_TRUSTED

10. Response Messages a TAM May Expect

A TAM expects some feedback from a remote device when a request message is delivered to a device. The following three types of responses SHOULD be supplied.

Type 1: Expect a valid TEE-generated response message

A valid TEE signed response may contain errors detected by a TEE, e.g. a TAM is trusted but some TAM-supplied data is missing, for example, SP ID doesn’t exist. TEE MUST be able to sign and encrypt.

If a TEE isn’t able to sign a response, the TEE returns an error to the OTrP Broker without giving any other internal information. The OTrP Broker will be generating the response.

Type 2: The OTrP Broker generated error message when TEE fails. OTrP Broker errors will be defined in this document.

A Type 2 message has the following format.

```json
{
    "OTrPBrokerError": {
        "ver": "1.0",
        "rid": "",
        "tid": "",
        "errcode": "ERR_AGENT_TEE_UNKNOWN | ERR_AGENT_TEE_BUSY"
    }
}
```

Type 3: OTrP Broker itself isn’t reachable or fails. A Client Application is responsible to handle error and respond the TAM in its own way. This is out of scope for this specification.
11. Basic Protocol Profile

This section describes a baseline for interoperability among the protocol entities, mainly, the TAM and TEE.

A TEE MUST support RSA algorithms. It is optional to support ECC algorithms. A TAM SHOULD use a RSA certificate for TAM message signing. It may use an ECC certificate if it detects that the TEE supports ECC according to the field "supportedSigAlgs" in a TEE response.

A TAM MUST support both RSA 2048-bit algorithm and ECC P-256 algorithms. With this, a TEE and TFW certificate can be either RSA or ECC type.

JSON signing algorithms

- RSA PKCS#1 with SHA256 signing : "RS256"
- ECDSA with SHA256 signing : "ES256"

JSON asymmetric encryption algorithms (describes key-exchange or key-agreement algorithm for sharing symmetric key with TEE):

- RSA PKCS#1 : "RSA1_5"
- ECDH using TEE ECC P-256 key and ephemeral ECC key generated by TAM : "ECDH-ES+A128W"

JSON symmetric encryption algorithms (describes symmetric algorithm for encrypting body of data, using symmetric key transferred to TEE using asymmetric encryption):

- Authenticated encryption AES 128 CBC with SHA256 :{"enc":"A128CBC-HS256"}

12. Attestation Implementation Consideration

It is important to know that the state of a device is appropriate before trusting that a device is what it says it is. The attestation scheme for OTrP must also be able to cope with different TEEs, including those that are OTrP compliant and those that use another mechanism. In the initial version, only one active TEE is assumed.

It is out of scope how the TAM and the device implement the trust hierarchy verification. However, it is helpful to understand what each system provider should do in order to properly implement an OTrP trust hierarchy.
In this section, we provide some implementation reference consideration.

12.1. OTrP Trusted Firmware

12.1.1. Attestation signer

It is proposed that attestation for OTrP is based on the TFW layer, and that further attestation is not performed within the TEE itself during Security Domain operations. The rationale is that the device boot process will be defined to start with a secure bootloader protected with a harden key in eFuse. The process releases attestation signing capabilities into the TFW once a trust boot has been established. In this way the release of the attestation signer can be considered the first "platform configuration metric", using Trust Computing Group (TCG) terminology.

12.1.2. TFW Initial Requirements

R1 The TFW must be possible for verification during boot
R2 The TFW must allow a public / private key pair to be generated during device manufacture
R3 The public key and certificate must be possible to store securely
R4 The private key must be possible to store encrypted at rest
R5 The private key must only be visible to the TFW when it is decrypted
R6 The TFW must be able to read a list of root and intermediate certificates that it can use to check certificate chains with. The list must be stored such that it cannot be tampered with
R7 Need to allow a TEE to access its unique TEE specific private key

12.2. TEE Loading

During boot, the TFW is required to start all of the root TEEs. Before loading them, the TFW must first determine whether the code sign signature of the TEE is valid. If TEE integrity is confirmed, the TEE may be started. The TFW must then be able to receive the identity certificate from the TEE (if that TEE is OTrP compliant). The identity certificate and keys will need to be baked into the TEE image, and therefore also covered by the code signer hash during the manufacturing process. The private key for the identity certificate must be securely protected. The private key for a TEE identity must
never be released no matter how the public key and certificate are released to the TFW.

Once the TFW has successfully booted a TEE and retrieved the identity certificate, the TFW will commit this to the platform configuration register (PCR) set, for later use during attestation. At minimum, the following data must be committed to the PCR for each TEE:

1. Public key and certificate for the TEE

2. TEE identifier that can be used later by a TAM to identify this TEE

12.3. Attestation Hierarchy

The attestation hierarchy and seed required for TAM protocol operation must be built into the device at manufacture. Additional TEEs can be added post-manufacture using the scheme proposed, but it is outside of the current scope of this document to detail that.

It should be noted that the attestation scheme described is based on signatures. The only decryption that may take place is through the use of a bootloader key.

12.3.1. Attestation Hierarchy Establishment: Manufacture

During manufacture the following steps are required:

1. A device-specific TFW key pair and certificate are burnt into the device. This key pair will be used for signing operations performed by the TFW.

2. TEE images are loaded and include a TEE instance-specific key pair and certificate. The key pair and certificate are included in the image and covered by the code signing hash.

3. The process for TEE images is repeated for any subordinate TEEs, which are additional TEEs after the root TEE that some devices have.

12.3.2. Attestation Hierarchy Establishment: Device Boot

During device boot the following steps are required:

1. The boot module releases the TFW private key by decrypting it with the bootloader key.
2. The TFW verifies the code-signing signature of the active TEE and places its TEE public key into a signing buffer, along with its identifier for later access. For a non-OTrP TEE, the TFW leaves the TEE public key field blank.

3. The TFW signs the signing buffer with the TFW private key.

4. Each active TEE performs the same operation as the TFW, building up their own signed buffer containing subordinate TEE information.

12.3.3. Attestation Hierarchy Establishment: TAM

Before a TAM can begin operation in the marketplace to support devices of a given TEE, it must obtain a TAM certificate from a CA that is registered in the trust store of devices with that TEE. In this way, the TEE can check the intermediate and root CA and verify that it trusts this TAM to perform operations on the TEE.

13. IANA Considerations

There are two IANA requests: a media type and list of error codes.

This section first requests that IANA assign a media type: application/otrp+json.

Type name: application

Subtype name: otrp+json

Required parameters: none

Optional parameters: none

Encoding considerations: Same as encoding considerations of application/json as specified in Section 11 of [RFC7159]

Security considerations: See Section 12 of [RFC7159] and Section 14 of this document

Interoperability considerations: Same as interoperability considerations of application/json as specified in [RFC7159]

Published specification: [TEEPArch]

Applications that use this media type: OTrP implementations

Fragment identifier considerations: N/A
Additional information:

Deprecated alias names for this type: N/A

Magic number(s): N/A

File extension(s): N/A

Macintosh file type code(s): N/A

Person to contact for further information: teep@ietf.org

Intended usage: COMMON

Restrictions on usage: none

Author: See the "Authors’ Addresses" section of this document

Change controller: IETF

The error code listed in the next section will be registered.

13.1. Error Code List

This section lists error codes that could be reported by a TA or TEE in a device in responding to a TAM request, and a separate list that OTrP Broker may return when the TEE fails to respond.

13.1.1. TEE Signed Error Code List

ERR_DEV_STATE_MISMATCH - A TEE will return this error code if the DSI hash value from TAM doesn't match the has value of the device’s current DSI.

ERR_SD_ALREADY_EXISTS - This error will occur if an SD to be created already exists in the TEE.

ERR_SD_NOT_EMPTY - This is reported if a target SD isn’t empty.

ERR_SDNAME_ALREADY_USED A TEE will return this error code if the new SD name already exists in the TEE.

ERR_REQUEST_INVALID - This error will occur if the TEE meets any of the following conditions with a request message: (1) The request from a TAM has an invalid message structure; mandatory information is absent in the message. undefined member or structure is included. (2) TEE fails to verify signature of the message or fails to decrypt its contents.
ERR_SPCERT_INVALID - If a new SP certificate for the SD to be updated is not valid, then the TEE will return this error code.

ERR_TA_ALREADY_INSTALLED - While installing a TA, a TEE will return this error if the TA has already been installed in the SD.

ERR_TA_INVALID - This error will occur when a TEE meets any of following conditions while checking validity of TA: (1) The TA binary has a format that the TEE can’t recognize. (2) The TEE fails to decrypt the encoding of the TA binary and personalization data. (3) If an SP isn’t registered with the SP SD where the TA will be installed.

ERR_TA_NOT_FOUND - This error will occur when the target TA doesn’t exist in the SD.

ERR_TEE_FAIL - If the TEE fails to process a request because of an internal error, it will return this error code.

ERR_TEE_RESOURCE_FULL - This error is reported when a device resource isn’t available anymore such as storage space is full.

ERR_TFW_NOT_TRUSTED - A TEE is responsible for determining that the underlying device firmware is trustworthy. If the TEE determines the TFW is not trustworthy, then this error will occur.

ERR_TAM_NOT_TRUSTED - Before processing a request, a TEE needs to make sure whether the sender TAM is trustworthy by checking the validity of the TAM certificate, etc. If the TEE finds that the TAM is not trustworthy, then it will return this error code.

ERR_UNSUPPORTED_CRYPTO_ALG - This error will occur if a TEE receives a request message encoded with cryptographic algorithms that the TEE doesn’t support.

ERR_UNSUPPORTED_MSG_VERSION - This error will occur if a TEE receives a message version that the TEE can’t deal with.

14. Security Consideration

14.1. Cryptographic Strength

The strength of the cryptographic algorithms, using the measure of ‘bits of security’ defined in NIST SP800-57 allowed for OTrP is:

- At a minimum, 112 bits of security. The limiting factor for this is the RSA-2048 algorithm, which is indicated as providing 112 bits of symmetric key strength in SP800-57. It is important that
RSA is supported in order to enhance the interoperability of the protocol.

- The option exists to choose algorithms providing 128 bits of security. This requires using TEE devices that support ECC P256.

The available algorithms and key sizes specified in this document are based on industry standards. Over time the recommended or allowed cryptographic algorithms may change. It is important that the OTrP allows for crypto-agility. In this specification, TAM and TEE can negotiate an agreed upon algorithm where both include their supported algorithm in OTrP message.

14.2. Message Security

OTrP messages between the TAM and TEE are protected by message security using JWS and JWE. The ‘Basic protocol profile’ section of this document describes the algorithms used for this. All OTrP TEE devices and OTrP TAMs must meet the requirements of the basic profile. In the future additional ‘profiles’ can be added.

PKI is used to ensure that the TEE will only communicate with a trusted TAM, and to ensure that the TAM will only communicate with a trusted TEE.

14.3. TEE Attestation

It is important that the TAM can trust that it is talking to a trusted TEE. This is achieved through attestation. The TEE has a private key and certificate built into it at manufacture, which is used to sign data supplied by the TAM. This allows the TAM to verify that the TEE is trusted.

It is also important that the TFW (trusted firmware) can be checked. The TFW has a private key and certificate built into it at manufacture, which allows the TEE to check that that the TFW is trusted.

The GetDeviceState message therefore allows the TAM to check that it trusts the TEE, and the TEE at this point will check whether it trusts the TFW.

14.4. TA Protection

A TA will be delivered in an encrypted form. This encryption is an additional layer within the message encryption described in the Section 11 of this document. The TA binary is encrypted for each target device with the device’s TEE SP AIK public key. A TAM can
either do this encryption itself or provide the TEE SP AIK public key to an SP such that the SP encrypts the encrypted TA for distribution to the TEE.

The encryption algorithm can use a random AES 256 key "taek" with a 16 byte random IV, and the "taek" is encrypted by the "TEE SP AIK public key". The following encrypted TA data structure is expected by a TEE:

```
"encrypted_ta_bin": {
"key": "<JWE enveloped data of a 256-bit symmetric key by the recipient’s TEEspaik public key>",
"iv": "<hex of 16 random bytes>",
"alg": "AESCBC",
"cipherdata": "<BASE64 encoded encrypted TA binary data>"
}
```

14.5. TA Personalization Data

An SP or TAM can supply personalization data for a TA to initialize for a device. Such data is passed through an InstallTA command from a TAM. The personalization data itself is (or can be) opaque to the TAM. The data can be from the SP without being revealed to the TAM. The data is sent in an encrypted manner in a request to a device such that only the device can decrypt. A device’s TEE SP AIK public key for an SP is used to encrypt the data. Here JWE enveloping is used to carry all encryption key parameters along with encrypted data.

```
"encrypted_ta_data": {
// "TA personalization data"
"key": "<JWE enveloped data of a 256-bit symmetric key by the recipient’s TEEspaik public key>",
"iv": "<hex of 16 random bytes>",
"alg": "AESCBC",
"cipherdata": "<BASE64 encoded encrypted TA personalization data>"
}
```

14.6. TA Trust Check at TEE

A TA binary is signed by a TA signer certificate. This TA signing certificate/private key belongs to the SP, and may be self-signed (i.e., it need not participate in a trust hierarchy). It is the responsibility of the TAM to only allow verified TAs from trusted SPs into the system. Delivery of that TA to the TEE is then the responsibility of the TEE, using the security mechanisms provided by the OTrP.
We allow a way for an (untrusted) application to check the trustworthiness of a TA. OTrP Broker has a function to allow a Client Application to query the information about a TA.

An application in the Rich O/S may perform verification of the TA by verifying the signature of the TA. The GetTAInformation function is available to return the TEE supplied TA signer and TAM signer information to the application. An application can do additional trust checks on the certificate returned for this TA. It might trust the TAM, or require additional SP signer trust chaining.

14.7. One TA Multiple SP Case

A TA for multiple SPs must have a different identifier per SP. A TA will be installed in a different SD for each respective SP.

14.8. OTrP Broker Trust Model

An OTrP Broker could be malware in the vulnerable REE. A Client Application will connect its TAM provider for required TA installation. It gets command messages from the TAM, and passes the message to the OTrP Broker.

The OTrP is a conduit for enabling the TAM to communicate with the device’s TEE to manage SDs and TAs. All TAM messages are signed and sensitive data is encrypted such that the OTrP Broker cannot modify or capture sensitive data.

14.9. OCSP Stapling Data for TAM Signed Messages

The GetDeviceStateRequest message from a TAM to a TEE shall include OCSP stapling data for the TAM’s signer certificate and for intermediate CA certificates up to the root certificate so that the TEE can verify the signer certificate’s revocation status.

A certificate revocation status check on a TA signer certificate is OPTIONAL by a TEE. A TAM is responsible for vetting a TA and the SP before it distributes them to devices. A TEE will trust a TA signer certificate’s validation status done by a TAM when it trusts the TAM.

14.10. Data Protection at TAM and TEE

The TEE implementation provides protection of data on the device. It is the responsibility of the TAM to protect data on its servers.
14.11. Privacy Consideration

Devices are issued with a unique TEE certificate to attest the device’s validity. This uniqueness also creates a privacy and tracking risk that must be mitigated.

The TEE will only release the TEE certificate to a trusted TAM (it must verify the TAM certificate before proceeding). OTrP is designed such that only a TAM can obtain the TEE device certificate and firmware certificate - the GetDeviceState message requires signature checks to validate the TAM is trusted, and OTrP delivers the device’s certificate(s) encrypted such that only that TAM can decrypt the response. A Client Application will never see the device certificate.

An SP-specific TEE SP AIK (TEE SP Anonymous Key) is generated by the protocol for Client Applications. This provides a way for the Client Application to validate some data that the TEE may send without requiring the TEE device certificate to be released to the client device rich O/S, and to optionally allow an SP to encrypt a TA for a target device without the SP needing to be supplied with the TEE device certificate.

14.12. Threat Mitigation

A rogue application may perform excessive TA loading. An OTrP Broker implementation should protect against excessive calls.

Rogue applications might request excessive SD creation. The TAM is responsible to ensure this is properly guarded against.

Rogue OTrP Broker could replay or send TAM messages out of sequence: e.g., a TAM sends update1 and update2. The OTrP Broker replays update2 and update1 again, creating an unexpected result that a client wants. "dsihash" is used to mitigate this. The TEE MUST store DSI state and check that the DSI state matches before it does another update.

Concurrent calls from a TAM to a TEE MUST be handled properly by a TEE. If multiple concurrent TAM operations take place, these could fail due to the "dsihash" being modified by another concurrent operation. The TEE is responsible for resolve any locking such that one application cannot lock other applications from using the TEE, except for a short term duration of the TAM operation taking place. For example, an OTrP operation that starts but never completes (e.g. loss of connectivity) must not prevent subsequent OTrP messages from being executed.
14.13. Compromised CA

A root CA for TAM certificates might get compromised. Some TEE trust anchor update mechanism is expected from device OEMs. A compromised intermediate CA is covered by OCSP stapling and OCSP validation check in the protocol. A TEE should validate certificate revocation about a TAM certificate chain.

If the root CA of some TEE device certificates is compromised, these devices might be rejected by a TAM, which is a decision of the TAM implementation and policy choice. Any intermediate CA for TEE device certificates SHOULD be validated by TAM with a Certificate Revocation List (CRL) or Online Certificate Status Protocol (OCSP) method.


The TEE SHOULD use validation of the supplied TAM certificates and OCSP stapled data to validate that the TAM is trustworthy.

Since PKI is used, the integrity of the clock within the TEE determines the ability of the TEE to reject an expired TAM certificate, or revoked TAM certificate. Since OCSP stapling includes signature generation time, certificate validity dates are compared to the current time.

14.15. Certificate Renewal

TFW and TEE device certificates are expected to be long lived, longer than the lifetime of a device. A TAM certificate usually has a moderate lifetime of 2 to 5 years. A TAM should get renewed or rekeyed certificates. The root CA certificates for a TAM, which are embedded into the trust anchor store in a device, should have long lifetimes that don’t require device trust anchor update. On the other hand, it is imperative that OEMs or device providers plan for support of trust anchor update in their shipped devices.

15. Acknowledgements

We thank Alin Mutu for his contribution to many discussion that helped to design the trust flow mechanisms, and the creation of the flow diagrams. We also thank the following people (in alphabetical order) for their input and review: Sangsu Baek, Rob Coombs, Dapeng Liu, Dave Thaler, and Pengfei Zhao.
16. References

16.1. Normative References


16.2. Informative References


Appendix A. Sample Messages

A.1. Sample Security Domain Management Messages

A.1.1. Sample GetDeviceState

A.1.1.1. Sample GetDeviceStateRequest

The TAM builds a "GetDeviceStateTBSRequest" message.

{  
    "GetDeviceStateTBSRequest": {  
        "ver": "1.0",  
        "rid": "8C6F9DBB-FC39-435c-BC89-4D3614DA2F0B",  
        "tid": "4F454A7F-002D-4157-884E-B0DD1A06A8AE",  
        "ocspdat": "c2FtcGxlIG1G9j3BkYXQgQjY0IGVuY29kZWQgQVNOMQ==",  
        "icaocspdat": "c2FtcGxlIG1GjYW9jc3BkYXQgQjY0IGVuY29kZWQgQVNOMQ==",  
        "supportedsigalgs": "RS256"  
    }  
}

The TAM signs "GetDeviceStateTBSRequest", creating "GetDeviceStateRequest"

{
    "GetDeviceStateRequest": {
        "payload": "eyJhbGciOiJSUzI1NiJ9",
        "header": {
            "x5c": ["ZXhhbXBsZSBBU04xIHNpZ251cBiJX0aWZpY2F0ZQ==", "ZXhhbXBsZSBBU04xIENBIGNlcnRpZmljYXRl"]
        },
        "signature": "c2FtcGxlIHNpZ25hdHVyZQ"
    }
}

A.1.1.2. Sample GetDeviceStateResponse

The TAM sends "GetDeviceStateRequest" to the OTrP Broker
The OTrP Broker obtains "dsi" from each TEE. (In this example there is a single TEE.)

The TEE obtains signed "fwdata" from firmware.

The TEE builds "dsi" - summarizing device state of the TEE.
The TEE encrypts "dsi", and embeds it into a "GetDeviceTEEStateTBSResponse" message.
The TEE signs "GetDeviceTEEStateTBSResponse" and returns it to the OTrP Broker. The OTrP Broker encodes "GetDeviceTEEStateResponse" into an array to form "GetDeviceStateResponse".
The TEE returns "GetDeviceStateResponse" back to the OTrP Broker, which returns message back to the TAM.

A.1.2. Sample CreateSD

A.1.2.1. Sample CreateSDRequest
Below is a sample message after the content is encrypted and encoded

{ "CreateSDTBSRequest": { "ver": "1.0", "rid": "req-01", "tid": "tran-01", "tee": "SecuriTEE", "nextds": "false", "dsihash": "Iu-c0-fGrpMmzbbtiWI1U8u7wMJE7IK8wkPJsVuf2js", "content": { "spid": "bank.com", "sdname": "sd.bank.com", "spcert": "MIIDFjCCAn-gAwIBAgIJAIk0Tat0tquDMA0GCSqGSIb3DQEBBQUAMQwxCzAJBgNVBAYTAlMCMGgGCCsGAQUFBwEBBhAgMDIwMgYDVR0TAQH/BAkMBgGOAwEBAgIuZCAwEAgYDVQQHEwJRUjEOMAwGA1UEBhMCVVMxGjBEczAcSIZDGYVjAAIBAgYEAYE9SAsMICSwGDA0tBhNDRzaHnD4ANBgkqhkiG9w0BAQsFADAMBgsGAIwCIYDZw==", "tamid": "TAM_x.acme.com", "did": "zAHkb0-SQh9U_OT8mR5dB-tygcqpUJ9_x07piw8WoM" } } }
A.1.2.2. Sample CreateSDResponse

```json
{
   "CreateSDTBSResponse": {
      "ver": "1.0",
      "status": "pass",
      "rid": "req-01",
      "tid": "tran-01",
      "content": {
         "did": "zAHkb0-SQh9U_OT8mR5dB-tygcqpuUJ9_x07pIiw8WoM",
         "sdname": "sd.bank.com",
         "teespaik": "AQABjY9KiwH3hkMmSAAN6CLXot525U85WNlWKAqzSToFde_CM8h-X6_EHK1gOxoyRx81KMqWb0Y8LCATwlytXy2kWa525imRh0s8Vqn6HDG0sJDZPDr9GnZR8pZX5ge_dWXB_uljMvDttc5iaWEJ8ZgcpLgtBTGLZnQoQbJtnllIE",
      }
   }
}
```

Below is the response message after the content is encrypted and encoded.

```json
{
   "CreateSDResponse": {
      "payload": "eyJDcmVhGVTFRCU1Jlc3BvbnNlIjp7InZlciI6IjEuMCIsInN0YXR1cyI6InBhcm93MiLCJyeWx7IjoiSmFtZiJ9",
      "signature": "nuQUsCTEBLeaRzuw7qliPIYEJ2eJfur05sT5YN03zFRCvljrvqMhTc_pw0Y9YWmpoWfpfcihwGEko9SgeeBnznmkZbp7kj56MmX4CKz90ape3-VI7yL9Yp0WNdRh3425eyfuapCy3lcXF1n5JBAAUnOzUg3RWxcU_yGnFsw"
   }
}
```
A.1.3. Sample UpdateSD

A.1.3.1. Sample UpdateSDRequest

```json
{
   "UpdateSDTBSRequest": {
      "ver": "1.0",
      "rid": "1222DA7D-8993-41A4-AC02-8A2807B31A3A",
      "tid": "4F454A7F-002D-4157-884E-B0DD1A06A8AE",
      "tee": "Primary TEE ABC",
      "nextdsi": "false",
      "dsihash": "IsOvwpzDk8Onw4bCrsKTJJsONwrbDrcJKYjVTw4vCu8OAw4JEm6zCsY8w4JCaKxW8Kf
w507",
      "content": { // NEEDS to BE ENCRYPTED
         "tamid": "id1.TAMxyz.com",
         "spid": "com.acmebank.spid1",
         "sdname": "com.acmebank.sdname1",
         "changes": {
            "newsdname": "com.acmebank.sdname2",
            "newspid": "com.acquirer.spid1",
            "spcert": "MIIDFjCCAn-
               gAwIBAgIJAIk0Tat0tquDMA0GCSqGSIb3QEBBQUAMGwxCzAJBgYDQYJKoZIhvc
               NAQEFBQADgYEAEMHrwEQ-LDa90T1N0mcLoRp6wF3QucJfuxBqRQG0xdXMKazI4V
               jBgaJxhey7Bzv6TZYDa-
               GRIzbyL1J47UpADQR3UiDzVxwCOMU6S5yUuhNSW_BeMViyj4lssX28iPnPwLUCV
               m1QVTHIL16afLCCRWXXcll15KGY29WOwDQ*
         }
      }
   }
}
```

A.1.3.2. Sample UpdateSDResponse

{
"UpdateSDTBSResponse": {
"ver": "1.0",
"status": "pass",
"rid": "1222DA7D-8993-41A4-AC02-8A2807B31A3A",
"tid": "4F454A7F-002D-4157-884E-B0DD1A06A8AE",
"content": {
"did": "MTZENTE5Qzc0Qzk0NkUxMzYxNzk0NjY4NTc3OTY4NTI4",
"teespaik": "AQABjY9KiwH3hkMmSAAN6CLXot525U85WN1WKAQz5T0dfe_CM8h-
X6_EHXLgOXoyRXaBiKMcWb0YZLCABTwlytdXy2kWa525imRho8Vq06HDGsJDZPDru9
GnZR8pxZX5ge_dWXB_uljMvDttc5iAWEJ8ZgcpLgtBTGLZnQoQbjtn1llIE",
"teespaiktype": "RSA"
}
}
}

A.1.4. Sample DeleteSD

A.1.4.1. Sample DeleteSDRequest

The TAM builds message - including data to be encrypted.

{
"DeleteSDTBSRequest": {
"ver": "1.0",
"rid": "\"712551F5-DFB3-43f0-9A63-663440B91D49\"",
"tid": "\"4F454A7F-002D-4157-884E-B0DD1A06A8AE\"",
"tee": "Primary TEE",
"nextdsi": "false",
"dsihash": "AAECAwQFBgcICQoLDA0ODg8",
"content": ENCRYPTED {
"tamid": "TAM1.com",
"sdname": "default.acmebank.com",
"deleteta": "1"
}
}

The TAM encrypts the "content".

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The TAM signs the "DeleteSDTBSRequest" to form a "DeleteSDRequest"
A.1.4.2. Sample DeleteSDResponse

The TEE creates a "DeleteSDTBSResponse" to respond to the "DeleteSDRequest" message from the TAM, including data to be encrypted.

```json
"DeleteSDTBSResponse": {
  "ver": "1.0",
  "status": "pass",
  "rid": "712551F5-DFB3-43f0-9A63-663440B91D49",
  "id": "4F544A7F-002D-4157-884E-B0DD1A06A8AE",
  "content": ENCRYPTED {
    "did": "MTZENTE5Qzc0Qzk0NkUxMzYxNzk0NTc3OTY4NTI=",
  }
}
```

The TEE encrypts the "content" for the TAM.
"DeleteSDTBSResponse": {
  "ver": "1.0",
  "status": "pass",
  "rid": "{712551F5-DFB3-43f0-9A63-663440B91D49}",
  "tid": "{4F454A7F-002D-4157-884E-B0DD1A06A8AE}",
  "content": {
    "protected": "eyJlbmMiOiJBMTI4Q0JDLUhTMjU2In0K",
    "recipients": [
      {
        "header": {
          "alg": "RSA1_5"
        },
        "encrypted_key": "QUVTMTI4IChDRUspIGtleSwgZW5jcnlwdGVkIHdpdGggVFNNIFJTQSBwdWJsaWMg
                        a2V5LCB1c2luZyBSU0ExXzUgcGFkZGluc2FtdWxk"
      },
      {
        "iv": "ySGmfZ69Y1cE1Lr5_SGbA",
        "ciphertext": "c2FtcGxlGzoiGRzaSBkYXRhIGVvY3J5cHRlZCB3aXRoIEFFUzEyOFCrZXkgZnJvbSBByZW
                        NpcG1ubmRzLmVxY3J5cHRlZF9rZXk",
        "tag": "c2FtcGxlIGF1dGhlbnRpY2F0aW9uIHRhZw"
      }
    ]
  }
}

The TEE signs "DeleteSDTBSResponse" to form a "DeleteSDResponse"
The TEE returns "DeleteSDResponse" back to the OTrP Broker, which returns the message back to the TAM.

A.2. Sample TA Management Messages

A.2.1. Sample InstallTA

A.2.1.1. Sample InstallTARequest
A.2.1.2. Sample InstallTAResponse

A sample to-be-signed response of InstallTA looks as follows.

```json
{
  "InstallTATBSResponse": {
    "ver": "1.0",
    "status": "pass",
    "rid": "24BE0B59-0AED-42A6-A381-817DFB7A1207",
    "tid": "4F454A7F-002D-4157-884E-B0DD1A06A8AE",
    "content": {
      "did": "MTZENTE5OzcQzk0NkUxMzYxNzk0Ny4NTc3OTY4NTI=",
      "dsi": {
        "tfwdata": {
```
"tbs": "ezRGNDUQQTdGLTAmKQtNDE1Nj04O0RFLUIwREQxQTA2QThBRX0="
"cert": "ZXhhbXBsZSBGVyBjZXJ0aWZpY2F0ZQ==",
"sigalg": "UlMyNTY=",
"sig": "c2FtcGxlIEZXIHNpZz5hdHVyZQ=="
},
"tee": {
  "name": "Primary TEE",
  "ver": "1.0",
  "cert": "c2FtcGxlIEFRFRk9zZXJ0aWZpY2F0ZQ==",
  "cacert": [ 
    "c2FtcGxlIENBIGNlcnRpZmljYXRlIDI=",
    "c2FtcGxlIENBIGNlcnRpZmljYXRlIDI="
  ],
  "sdlist": {
    "cnt": "1",
    "sd": [ 
      { 
        "name": "com.acmebank.sdname1",
        "spid": "com.acmebank.spid1",
        "talist": [ 
          { 
            "taid": "com.acmebank.taid.banking",
            "taname": "Acme secure banking app"
          },
          { 
            "taid": "acom.acmebank.taid.loyalty.rewards",
            "taname": "Acme loyalty rewards app"
          }
        ]
      } ]
    },
  "teeaiklist": [ 
    { 
      "spaik": "c2FtcGxlIEFTTjEgZW5jb2Rl", 
      "spaiktype": "RSA",
      "spid": "acmebank.com"
    }
  ]
}
A.2.2. Sample UpdateTA

A.2.2.1. Sample UpdateTARequest

```
{
"UpdateTATBSRequest": {
  "ver": "1.0",
  "rid": "req-2",
  "tid": "tran-01",
  "tee": "SecuriTEE",
  "nextdsi": "false",
  "dsihash": "gwju1_SMZks3pqUSN1-eL1aViwGXNAxk0AIKW79dn4U",
  "content": {
    "tamid": "TAM1.acme.com",
    "spid": "bank.com",
    "sdname": "sd.bank.com",
    "taid": "sd.bank.com.ta"
  },
  "encrypted_ta": {
    "key": "XzmAn_RDVk3IozMwNWhiB6fmZ1Is1YUvMK1QAy_UDozlcvGGsRG09bT0A440aYMqLtG1LKyPPoJjCjijdaHgamaJgRSc4Je2otpNEagsahvDNor3C5QqkRvxW7Vo2NKgL_A892HGeHkJVshYm1CFQ-BhiJ4NAytFw1qvC_oc",
    "iv": "AxY8DcTDgsLsbGljb3RoZQ",
    "alg": "AESCBC",
    "ciphernewtadata": "KHqOGxG71bIF_14pG4_UX9DBjocWkIAZvVE-U-67NaKxryGoKeWr2spRwfdU2KwaNncHoYGwEtcb7XyNbO28zumstep4nHWbAlXZYTNkEACBPwuG3I1HADO"
  }
}
}
{
"UpdateTARequest": {
  "payload": "eyJVcGRhdGVVQVRCU1Jlc2xVc3QiOnsidmyIjoiMS4wIiwicmlkIjoicmVuLiTIII1LCJ0awQjoiJcmFuLTATxiwGdGVVljoiU2jdvXyPVEFV1iwbmV4dGRzaS16IzZhbHNlIiw1ZHnpaGFzaC16I3anVxzl1Wmtzm3BxXVNNOMSi1TDFhVml3IhoQXhrmMJE5c1s30RWuNFU1LCjhb250ZW50Ij7I61byb3RLyRlZCI6ImV5SmxibUlplT2lKQk1USTRHRHepeTFV0VE1qVTJObjAIc3Y2NpG1ibnRzIjpbeyjoZWFkZXZ1IonsiYWxnIjoi0XBMV81In0sImVuY3J5cHR1ZXR1dG1zIjoiYm1Bb19SRFZm0I0vek13TldoaUI2ZmlabElzNVlVdki1LbFFAi9VRG9aMWZ2R0dzUkbvOWJUUEE0NDDBhWU1nTHRHaXlXeXBrSmddZ2lqZGFIZZFtYUnpUIN3EplMn90cG5FRWenc2FEdkRo2FYTUNDNW5HUWWmUnhXN12ZYkJk5L20wB0dkySEDlISgtKvN0W0X1YVsR1EtQmhpSSjROXIXrRmds3UNfb2MifV0sIm12IjoiQXhZ0ERDdERhR2xXyksam1zUm9aUSIsImNpcGlcnRleHQ1o1JITCwVXRZVEtWQm7XRFJuMIow"
}
```
A.2.2.2. Sample UpdateTAResponse

{ "UpdateTATBSResponse": {
  "ver": "1.0",
  "status": "pass",
  "rid": "req-2",
  "tid": "tran-01",
  "content": {
    "did": "zAHkb0-SQh9U_OT8mR5dB-tygcqpUJ9_x07pIiw8WoM"
  }
}
}
"UpdateTAResponse": {
  "payload":
  eyjVCcGRhdGVQVVRQCU1Jlc3BvbmNlIjtpI2NzlciI6IjEuMCIeInN0YXRlcyI6InBhc3Mi
  LCJyYWx1IjoiJzXETmNiIi structs.IsStruct{} RzJb250ZW50IjpwIjByb3R1Y3R1
  ZCI6I6mVSxib1IptIzIzQkI6I12TRMRMeETVFVoVIElqVTJYbAjiLCljYWx1NWNpcGlbn
  rune.RzJbeyJoZWFkZXIiOnsiYWNyIjo1NBMV8iOnsImVuY3J5ciR1ZjFzX1oiIjFAUUKU
  IoJLTEMbFHDGJFy01MDJdtodogxM1muRdYQWx1MTUfUXVZRXRim55VSowNFc2MnbK
  YW5ScRFEYuU0dSVgjBvZQfRQg0MDkuU01hcbE1EZ3BYdXFlci1JZ0ttN31dCZ2N3
  VXVQyTRUR3gwU01INzCdI292dnBNAdfMnXh2c2ZhqdFBAqmxwTnJ2bNiBzY3Fob1i1u
  bzbETm5SVAx1I0t1Vs1im12IjoiQXh0OzEhRdzErhRz2xYksdamIzUm9aOUI1ImpcGhl
  cnRieHQI0Ijwco2dGtyaGJX01meE9GMU5HdFuctfMMeVBidV9KWh9jbllycGWw
  eTNPQOHh60TitaWpWR1ZYkw5WhGlY1YfeWFNTZ0Z1X1J0dEkwV3B4UmRody1Is1hRz2y16
  Yk02zbdNNk11MVJYMUMyebEZvaG5rTknSb25qNjd2TDNgd3ZnXzFudUlpataGfX19",
  "protected": "eyJhbGciOiJSUZI1NiJ9",
  "header": {
    "kid": "e9bc097a-ce51-4036-9562-2dade882db0d",
    "signer":
  MIIC3cCCAkigAwIBAgIHBYOMAKGCSgGCSqGSIb3DQEBCwUAA4GCMEMBQAwGgYDVQQD
  TmVVRQIDAQABIwAQQJAgIwMDA2MS4wIzAlAQMgZzAbBgNVHRMEbDAUEwDwQJMB0GA1UdI
  wQEBAAQJAzJGMA0GCSqGSIb3DQEowDAQIYDVQQDDBVObnRlZ3JhdGFub3duIENvbGUg
  Q29kZSBncmFtcGluZ3MgaXMgZmVjdCBfZ3N3ZWVuZ3JhdGFub3duaSBQaG90b3N0IHRv
  c3RlZCBxdWVzdCBBdXRob3IgZ2VuZ2l2ZSB0aGlzIGFwcGxlIHRvZ3MgbGFyaWluZyBy
  dGVzdCBlcmFkIGZ1bmN0aW9uIG9vc2ggb3V0IHN0cmluZwYXGjI3OTAgMA0GCSqGSIb3DQ
  gEBOhEBMA0GCSqGSIb3DQEhBgVCMA4GA1UdDwEB/wQEAwIBAgIwMDA2MSEwHgYDVQQD
  DBNfYmFyQ2FsaWZvcm5pYTBfMTE4MDk4MzQ3MjQxNTkxZjA8
  Y29t
  eTNTbDZoOVhXaW50aW5mZCByYWxsTWNiQ0Ff
A.2.3. Sample DeleteTA

A.2.3.1. Sample DeleteTAResquest

```json
{
   "DeleteTATBSRequest": {
      "ver": "1.0",
      "rid": "req-2",
      "tid": "tran-01",
      "tee": "SecuriTEE",
      "nextdsi": "false",
      "dsihash": "gwjul_9MZks3pqUSN1-eL1aViwGXNAxk0AIKW79dn4U",
      "content": {
         "tamid": "TAM1.acme.com",
         "sdname": "sd.bank.com",
         "taid": "sd.bank.com.ta"
      }
   }
}
```
"DeleteTARequest": {
  "payload":
  "eyJEZWxldGVUQVRCU1JlcXVlc3QiOnsidmVyIjoiMS4wIiwicmlkIjoicmVxLTIiLCJ0aWQiOiJ0cmFuLTAxIiwidGVlIjoiU2VjdXJpVEVFIiwibmV4dGRzaSI6ImZhbHNlIiwiZHNpaGFzaCI6Imd3anVsX1NWMtzmM3bxVVNOM01TDFhVml3R1hQXhrMEFJS1c3OWRuNFU1LCjbZjBzOW5ZOTIjOnsia2V5IjoidmVyIiwiZmFja2l0ZSI6IiIsfX0=
}
}
"protected": "eyJhbGciOiJSUzI1NiJ9",
"header":
  "kid": "e9bc097a-ce51-4036-9562-d2ade882db0d",
  "signer": "MIIC3zCCAkigAwIBAgIJAJf2fFkE1BYOM4GA1UEAwwHVGdIY29yZGEwJAYDVQQHMRQIjIwMAYDVQQKDBhJbnRlcm5ldCBXaWRnaXRzIEluc3QuY29tMB8GA1UECgwYS2FsdGVyIHJhbmQgQ0EwHhcNMTUwNzAyMDkwMTE4WhcNMjAwNjMwMDkwMTE4WjBEiTAdBgNVHQ4EFgQgUfCD2XmGseluZACJv5Z1ldiH2ovdI5TAkCvqT1OEUkEwEQQiA8IFcYDQYJKoZIhvcNAQcDBgkqhkiG9w0BAQsFAAOCAQ8eKCIvR1a4eDaWz4p8y2wuqP1JLXK9s5pQBAgIY2MEbZ4OQPEQhjTImiTMJQwYb0dOsp02CgydRqgXtGvZPCKldJFMvym6gBw5kskwQsHwS5OAS6vhKDSt4vHm1LZ7GhUcLWQp9SvJMnFVDJbMhhH46rWb23h714HnU8g5xOro4T7EBmYq6w8xLJLcD01hRyIO1a5VuTfB3Bp6J7q36aRb9kxUJbH0PqU9vBQHibbyLiMXJ7b7k5Rr09y4UkxUgGUGvjo2Zy2BQs1c0X3p5T2khE3wuDjMrDjJJsB2q9CQ0Zk46AajRv7xOx0qkLmoMO9sDvZP4zYdwwK5g/ koH9D7gS8QcFcbT8m6L1rCzmp9vD8OzuVQx4vF9FwJ7oYUPWVQiZbcy8S2xP/vXyVA3aVJzBzvU1/3K3X6D6HMKqGz2M京津冀သိရာဇာ
"signature": "BZS0_Ab6pqvGNXe5lq3yakyWSQeik9KLVsnimwNjCcyMtyB9bwvb1ILZba3IjiFe_3F9bIqPpSytG50f2TePK7c7p5jwDw= 3kK7HkHcFPJd-PpMmFQvrXzAIv8vbQ9m1jic621NOV2e5z5v28VFfjGoRgq225W7FvweW"
A.2.3.2. Sample DeleteTAResponse

```json
{
    "DeleteTATBSResponse": { 
        "ver": "1.0",
        "status": "pass",
        "rid": "req-2",
        "tid": "tran-01",
        "content": { 
            "did": "zAHkb0-SQh9U_OT8mR5dB-tygcqUJ9_x07pIiw8WoM"
        }
    }
}
```
{ "DeleteTAResponse": {
    "payload": "ew0KCSJEZWxldGVUQVRCU1Jlc3BvbnNlIjogew0KCSJz
    "protected": "eyJhbGciOiJSUzI1NiJ9",
    "header": {
      "kid": "e9bc097a-ce51-4036-9652-62ade882db0d",
      "signer": "MIIC3zCCAkigAwIBAgIJA2f2fEKBYOMA0GCSqGSIb3DQEBAUAMIGo
    "signature": "DfoBOetNelKsnAe_m4Z9K5u8HJpCxD6D22J8GDUExlIhSR1aDuDCQm6QzmjdkFdxAz5TRYl6zpPCZqgSToN_g1TZxqxEv6V
    "signature": "DfoBOetNelKsnAe_m4Z9K5u8HJpCxD6D22J8GDUExlIhSR1aDuDCQm6QzmjdkFdxAz5TRYl6zpPCZqgSToN_g1TZxqxEv6V
  }
}

A.3. Example OTrP Broker Option

The most popular TEE devices today are Android powered devices. In an Android device, an OTrP Broker can be a bound service with a service registration ID that a Client Application can use. This option allows a Client Application not to depend on any OTrP Broker SDK or provider.

An OTrP Broker is responsible to detect and work with more than one TEE if a device has more than one. In this version, there is only one active TEE such that an OTrP Broker only needs to handle the active TEE.

Appendix B. Contributors

- Brian Witten
  Symantec
  brian_witten@symantec.com

- Tyler Kim
  Solacia
  tylerkim@iotrust.kr

Authors’ Addresses

Mingliang Pei
Symantec
350 Ellis St
Mountain View, CA 94043
USA

Email: mingliang_pei@symantec.com

Andrew Atyeo
Intercede
St. Mary’s Road, Lutterworth
Leicestershire, LE17 4PS
Great Britain

Email: andrew.atyeo@intercede.com
Abstract

This document specifies the HTTP transport for the Open Trust Protocol (OTrP), which is used to manage code and configuration data in a Trusted Execution Environment (TEE). An implementation of this document can run outside of any TEE, but interacts with an OTrP implementation that runs inside a TEE.

Status of This Memo

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1. Introduction

Trusted Execution Environments (TEEs), including Intel SGX, ARM TrustZone, Secure Elements, and others, enforce that only authorized code can execute within the TEE, and any memory used by such code is protected against tampering or disclosure outside the TEE. The Open Trust Protocol (OTrP) is designed to provision authorized code and configuration into TEEs.

To be secure against malware, an OTrP implementation (referred to as an OTrP "Agent" on the client side, and a "Trusted Application Manager (TAM)" on the server side) must themselves run inside a TEE. However, the transport for OTrP, along with typical networking stacks, need not run inside a TEE. This split allows the set of highly trusted code to be kept as small as possible, including allowing code (e.g., TCP/IP) that only sees encrypted messages to be kept out of the TEE.

The OTrP specification [I-D.ietf-teep-opentrustprotocol] describes the behavior of OTrP Agents and TAMs, but does not specify the details of the transport, an implementation of which is referred to as a "Broker". The purpose of this document is to provide such
details. That is, the HTTP transport for OTrP is implemented in a
Broker (typically outside a TEE) that delivers messages up to an OTrP
implementation, and accepts messages from the OTrP implementation to
be sent over a network.

2. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT",
"SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and
"OPTIONAL" in this document are to be interpreted as described in BCP
14 [RFC2119] [RFC8174] when, and only when, they appear in all
capitals, as shown here.

This document also uses various terms defined in
[I-D.ietf-teep-architecture], including Trusted Execution Environment
(TEE), Trusted Application (TA), Trusted Application Manager (TAM),
Agent, and Broker.

3. Use of Abstract APIs

This document refers to various APIs between a Broker and an OTrP
implementation in the abstract, meaning the literal syntax and
programming language are not specified, so that various concrete APIs
can be designed (outside of the IETF) that are compliant.

It is common in some TEE architectures (e.g., SGX) to refer to calls
into a Trusted Application (TA) as "ECALLs" (or enclave-calls), and
calls out from a Trusted Application (TA) as "OCALLs" (or out-calls).

In other TEE architectures, there may be no OCALLs, but merely data
returned from calls into a TA. This document attempts to be agnostic
as to the concrete API architecture. As such, abstract APIs used in
this document will refer to calls into a TA as API calls, and will
simply refer to "passing data" back out of the TA. A concrete API
might pass data back via an OCALL or via data returned from an API
call.

This document will also refer to passing "no" data back out of a TA.
In an OCALL-based architecture, this might be implemented by not
making any such call. In a return-based architecture, this might be
implemented by returning 0 bytes.

4. Use of HTTP as a Transport

This document uses HTTP [I-D.ietf-httpbis-semantics] as a transport.
When not called out explicitly in this document, all implementation
recommendations in [I-D.ietf-httpbis-bcp56bis] apply to use of HTTP
by OTrP.
Redirects MAY be automatically followed, and no additional request headers beyond those specified by HTTP need be modified or removed upon a following such a redirect.

Content is not intended to be treated as active by browsers and so HTTP responses with content SHOULD have the following headers as explained in Section 4.12 of [I-D.ietf-httpbis-bcp56bis]:

- Content-Type: application/otrp+json
- Cache-Control: no-store
- X-Content-Type-Options: nosniff
- Content-Security-Policy: default-src ’none’
- Referrer-Policy: no-referrer

Only the POST method is specified for TAM resources exposed over HTTP. A URI of such a resource is referred to as a "TAM URI". A TAM URI can be any HTTP(S) URI. The URI to use is configured in an OTrP Agent via an out-of-band mechanism, as discussed in the next section.

When HTTPS is used, TLS certificates MUST be checked according to [RFC2818].

5. Client Broker Behavior

5.1. Receiving a request to install a new Trusted Application

When the Broker receives a notification (e.g., from an application installer) that an application has a dependency on a given Trusted Application (TA) being available in a given type of TEE, the notification will contain the following:

- A unique identifier of the TA

- Optionally, any metadata to pass to the OTrP Agent. This might include a TAM URI provided in the application manifest, for example.

- Optionally, any requirements that may affect the choice of TEE, if multiple are available to the Broker.

When such a notification is received, the Broker first identifies in an implementation-dependent way which TEE (if any) is most appropriate based on the constraints expressed. If there is only one TEE, the choice is obvious. Otherwise, the choice might be based on factors such as capabilities of available TEE(s) compared with TEE requirements in the notification.
The Broker then informs the OTrP Agent in that TEE by invoking an appropriate "RequestTA" API that identifies the TA needed and any other associated metadata. The Broker need not know whether the TEE already has such a TA installed or whether it is up to date.

The OTrP Agent will either (a) pass no data back, (b) pass back a TAM URI to connect to, or (c) pass back a message buffer and TAM URI to send it to. The TAM URI passed back may or may not be the same as the TAM URI, if any, provided by the broker, depending on the OTrP Agent’s configuration. If they differ, the Broker MUST use the TAM URI passed back.

5.1.1. Session Creation

If no data is passed back, the Broker simply informs its client (e.g., the application installer) of success.

If the OTrP Agent passes back a TAM URI with no message buffer, the TEEP Broker attempts to create session state, then sends an HTTP(S) POST to the TAM URI with an "Accept: application/otrp+json" header and an empty body. The HTTP request is then associated with the Broker’s session state.

If the OTrP Agent instead passes back a TAM URI with a message buffer, the TEEP Broker attempts to create session state and handles the message buffer as specified in Section 5.2.

Session state consists of:

- Any context (e.g., a handle) that identifies the API session with the OTrP Agent.
- Any context that identifies an HTTP request, if one is outstanding. Initially, none exists.

5.2. Getting a message buffer back from an OTrP Agent

When a message buffer (and TAM URI) is passed to a Broker from an OTrP Agent, the Broker MUST do the following, using the Broker’s session state associated with its API call to the OTrP Agent.

The Broker sends an HTTP POST request to the TAM URI with "Accept: application/otrp+json" and "Content-Type: application/otrp+json" headers, and a body containing the OTrP message buffer provided by the OTrP Agent. The HTTP request is then associated with the Broker’s session state.
5.3. Receiving an HTTP response

When an HTTP response is received in response to a request associated with a given session state, the Broker MUST do the following.

If the HTTP response body is empty, the Broker’s task is complete, and it can delete its session state, and its task is done.

If instead the HTTP response body is not empty, the Broker calls a "ProcessOTrPMessage" API (Section 6.2 of [I-D.ietf-teep-opentrustprotocol]) to pass the response body to the OTrP Agent associated with the session. The OTrP Agent will then pass no data back, or pass pack a message buffer.

If no data is passed back, the Broker’s task is complete, and it can delete its session state, and inform its client (e.g., the application installer) of success.

If instead the OTrP Agent passes back a message buffer, the TEEP Broker handles the message buffer as specified in Section 5.2.

5.4. Handling checks for policy changes

An implementation MUST provide a way to periodically check for OTrP policy changes. This can be done in any implementation-specific manner, such as:

A) The Broker might call into the OTrP Agent at an interval previously specified by the OTrP Agent. This approach requires that the Broker be capable of running a periodic timer.

B) The Broker might be informed when an existing TA is invoked, and call into the OTrP Agent if more time has passed than was previously specified by the OTrP Agent. This approach allows the device to go to sleep for a potentially long period of time.

C) The Broker might be informed when any attestation attempt determines that the device is out of compliance, and call into the OTrP Agent to remediate.

The Broker informs the OTrP Agent by invoking an appropriate "RequestPolicyCheck" API. The OTrP Agent will either (a) pass no data back, (b) pass back a TAM URI to connect to, or (c) pass back a message buffer and TAM URI to send it to. Processing then continues as specified in Section 5.1.1.
5.5. Error handling

If any local error occurs where the Broker cannot get a message buffer (empty or not) back from the OTrP Agent, the Broker deletes its session state, and informs its client (e.g., the application installer) of a failure.

If any HTTP request results in an HTTP error response or a lower layer error (e.g., network unreachable), the Broker calls the OTrP Agent’s "ProcessError" API, and then deletes its session state and informs its client of a failure.

6. Server Broker Behavior

6.1. Receiving an HTTP POST request

When an HTTP POST request is received with an empty body, the Broker invokes the TAM’s "ProcessConnect" API. The TAM will then pass back a (possibly empty) message buffer.

When an HTTP POST request is received with a non-empty body, the Broker calls the TAM’s "ProcessOTrPMessage" API to pass it the request body. The TAM will then pass back a (possibly empty) message buffer.

6.2. Getting an empty buffer back from the TAM

If the TAM passes back an empty buffer, the Broker sends a successful (2xx) response with no body.

6.3. Getting a message buffer from the TAM

If the TAM passes back a non-empty buffer, the Broker generates a successful (2xx) response with a "Content-Type: application/otrp+json" header, and with the message buffer as the body.

6.4. Error handling

If any error occurs where the Broker cannot get a message buffer (empty or not) back from the TAM, the Broker generates an appropriate HTTP error response.

7. Sample message flow

1. An application installer determines (e.g., from an app manifest) that the application has a dependency on TA "X", and passes this notification to the Client Broker. The Client Broker picks an
OTrP Agent (e.g., the only one available) based on this notification.

2. The Client Broker calls the OTrP Agent’s "RequestTA" API, passing TA Needed = X.

3. The OTrP Agent finds that no such TA is already installed, but that it can be obtained from a given TAM. The OTrP Agent passes the TAM URI (e.g., "https://example.com/tam") to the Client Broker. (If the OTrP Agent already had a cached TAM certificate that it trusts, it could skip to step 9 instead and generate a GetDeviceStateResponse.)

4. The Client Broker sends an HTTP POST request to the TAM URI:

   POST /tam HTTP/1.1
   Host: example.com
   Accept: application/otrp+json
   Content-Length: 0
   User-Agent: Foo/1.0

5. The Server Broker receives the HTTP POST request, and calls the TAM’s "ProcessConnect" API.

6. The TAM generates an OTrP message (typically GetDeviceStateRequest is the first message) and passes it to the Server Broker.

7. The Server Broker sends an HTTP successful response with the OTrP message in the body:

   HTTP/1.1 200 OK
   Content-Type: application/otrp+json
   Content-Length: [length of OTrP message here]
   Server: Bar/2.2
   Cache-Control: no-store
   X-Content-Type-Options: nosniff
   Content-Security-Policy: default-src ’none’
   Referrer-Policy: no-referrer

   [OTrP message here]
8. The Client Broker gets the HTTP response, extracts the OTrP message and calls the OTrP Agent’s "ProcessOTrPMessage" API to pass it the message.

9. The OTrP Agent processes the OTrP message, and generates an OTrP response (e.g., GetDeviceStateResponse) which it passes back to the Client Broker.

10. The Client Broker gets the OTrP message buffer and sends an HTTP POST request to the TAM URI, with the OTrP message in the body:

    POST /tam HTTP/1.1
    Host: example.com
    Accept: application/otrp+json
    Content-Type: application/otrp+json
    Content-Length: [length of OTrP message here]
    User-Agent: Foo/1.0

    [OTrP message here]

11. The Server Broker receives the HTTP POST request, and calls the TAM’s "ProcessOTrPMessage" API.

12. Steps 6–11 are then repeated until the TAM passes no data back to the Server Broker in step 6.

13. The Server Broker sends an HTTP successful response with no body:

    HTTP/1.1 204 No Content
    Server: Bar/2.2

14. The Client Broker deletes its session state.

8. Security Considerations

   Although OTrP is protected end-to-end inside of HTTP, there is still value in using HTTPS for transport, since HTTPS can provide additional protections as discussed in Section 6 of [I-D.ietf-httpbis-bcp56bis]. As such, Broker implementations MUST support HTTPS. The choice of HTTP vs HTTPS at runtime is up to policy, where an administrator configures the TAM URI to be used, but it is expected that real deployments will always use HTTPS TAM URIs.
9. IANA Considerations

[[NOTE: This section should probably be moved to the OTrP spec.]]

This section requests that IANA assign the "application/otrp+json" media type.

Type name: application

Subtype name: otrp+json

Required parameters: none

Optional parameters: none

Encoding considerations: Same as encoding considerations of application/json as specified in Section 11 of [RFC7159].

Security considerations: See Section 12 of [RFC7159] and Section 8 of this document.

Interoperability considerations: Same as interoperability considerations of application/json as specified in [RFC7159].

Published specification: [I-D.ietf-teep-opentrustprotocol]

Applications that use this media type: OTrP implementations.

Fragment identifier considerations: N/A

Additional information:
   Deprecated alias names for this type: N/A
   Magic number(s): N/A
   File extension(s): N/A
   Macintosh file type code(s): N/A

Person & email address to contact for further information:
teep@ietf.org

Intended usage: COMMON

Restrictions on usage: none

Author: See the "Authors’ Addresses" section of this document.

Change controller: IETF
10. References

10.1. Normative References

[I-D.ietf-httpbis-semantics]

[I-D.ietf-teep-opentrustprotocol]


10.2. Informative References

[I-D.ietf-httpbis-bcp56bis]
Nottingham, M., "Building Protocols with HTTP", draft-ietf-httpbis-bcp56bis-08 (work in progress), November 2018.

[I-D.ietf-teep-architecture]

Author’s Address

David Thaler
Microsoft

EMail: dthaler@microsoft.com