

TCG Infrastructure Working Group A CMC Profile for AIK Certificate Enrollment

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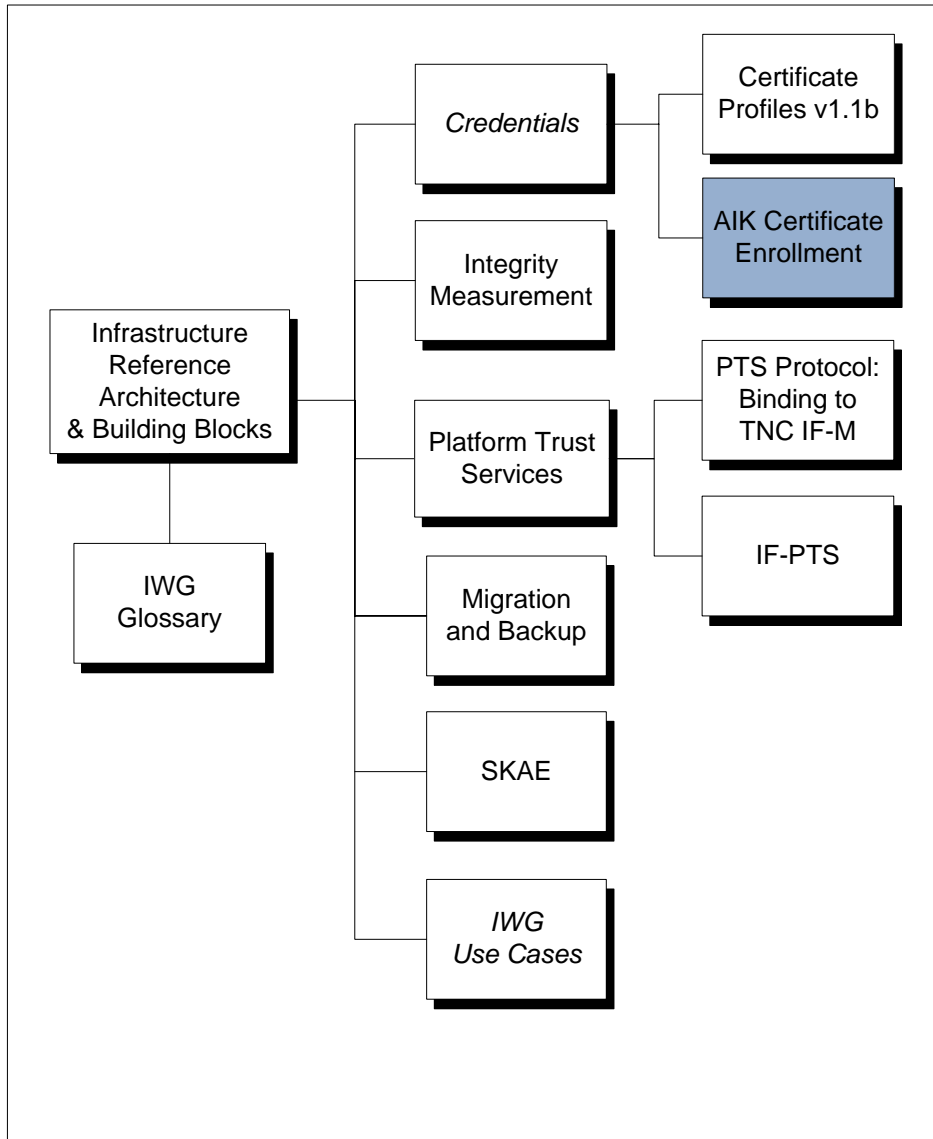
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IWG Document Roadmap



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1 Scope and Audience

The TCG Infrastructure Working Group (IWG) aims to improve interoperability among systems implementing TCG technology, and to that end, has defined a reference architecture [2] which clarifies the use of existing infrastructure technologies. A significant portion of the work done by IWG pertains to Trusted Platform Module (TPM) credentials, and while much of the complex groundwork has already been laid, the problems surrounding TPM credential enrollment have only been addressed at a high level thus far.

Typically, Endorsement Key (EK) Credentials and Platform Credentials are expected to be issued once during the system's supply chain manufacturing processes (e.g. by the TPM manufacturer and OEM respectively), while AIK Credentials are expected to be issued as needed, potentially on a per user or application basis. Thus, credentials containing AIKs are within the realm of the system and application domain administrators, and these will require interoperable support from a variety of vendors.

In order to achieve broad interoperability, it is important to enumerate the issues and considerations relating to AIK enrollment which arise in a representative sampling of enrollment scenarios, and to provide clear guidance on the various ways in which these may be addressed. In addition, specification of a reference enrollment protocol serves to simultaneously enhance our understanding of the related issues while providing a serviceable solution for a significant percentage of TPM deployment models.

It is important to note that while the primary motivation for this specification is to address issues surrounding AIK enrollment, EK and/or platform certificate enrollment scenarios have much in common with AIK enrollment. Furthermore, EK/Platform certificates are nominally required as part of the AIK enrollment process, but since such certificates are often not issued by manufacturers today, some sort of post-manufacturing provisioning support is needed. Hence, this specification strives to define a protocol that may be adapted for use in both manufacturing and post-manufacturing EK/platform certificate enrollment scenarios.

Architects, designers, developers and technologists who are interested in the development, deployment and interoperation of trusted systems may find this document helpful in providing both abstract and implementation-specific insights for achieving interoperation between TCG-based systems. But in particular, architects and developers of TPM-related enrollment infrastructure solutions will find this document highly relevant.

1.1 Prerequisites

There are a number of important prerequisites for maximizing understanding of this document. While it is best to have read all of the following, at minimum, these documents should be available for reference:

- The latest version of "TCG Infrastructure Working Group Reference Architecture for Interoperability" [2]
- The latest "TCG Credential Profile" specification [4]
- The latest "TNC Architecture for Interoperability" specification [23]
- The latest "Subject Key Attestation Evidence Extension" specification [16]
- The latest "Certificate Management Messages over CMS" specification[8]

In addition, familiarity with Public Key Infrastructure (PKI) and related technologies is assumed, and ready access to related reference works may be important to assist in understanding the material in this specification.

1.2 Terminology

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 RFC 2119 [22].

SECTION I: Requirements and Design

2 Background

This section provides background material to assist in interpreting the balance of this specification. Note that TCG infrastructure is complex, and much excellent documentation already exists. Therefore, here we give only the most basic descriptions, and include references to existing documentation for those cases in which more detail might be desired.

2.1 Credential Refresher

This section gives a brief overview of the TCG credentials relevant to this specification. For more detail, see [\[3\]](#).

2.1.1 Endorsement Key Credential

The EK credential contains the public EK, as well as various assertions regarding the security qualities and provenance of the TPM. This credential is sometimes provided by the TPM manufacturer, but may also be provided by the platform manufacturer. In some cases, no EK credential is provided or present in devices when they are delivered to end consumers, so these may ultimately need to be provided by or for the consumer (e.g., by a deploying IT department).

The EK credential may be considered to be privacy-sensitive, as in typical deployments, only one EK is created over the lifetime of a TPM, implying that the EK uniquely identifies the TPM in which it resides.

2.1.2 Platform Credential

A platform credential attests that a specific platform contains a unique TPM permanently associated with a static or dynamic root of trust. For comprehensive definitions of these terms, see [\[4\]](#). The platform credential is typically issued by the platform manufacturer, and contains a reference to the associated EK certificate, as well as assertions regarding the platform manufacturer, platform model, and platform security properties (among other things).

The platform credential has been specified as an X.509v3 Attribute Certificate (as it contained no public key), but a lack of widespread attribute certificate support led to the pragmatic compromise of simply making this a standard X.509v3 certificate containing a copy of the EK public key (the Unified Credential [\[4\]](#)).

2.1.3 Attestation Identity Key (AIK) Credential

The AIK credential is issued by an “Attestation Certification Authority” (ACA, defined below in section 2.2) that is trusted to validate the various credentials associated with the EK and platform, and to honor the privacy policies of the client. The primary goals of the AIK certificate are to attest that a TPM contains the AIK, that the AIK is tied to valid EK and platform credentials, and that use of the AIK is restricted to the operations defined in the TPM specification. The present specification is primarily concerned with the operation of the Attestation CA, and with the interaction between a platform and this CA.

2.2 Attestation CA

The primary Certification Authority (CA) associated with the TPM has been referred to in previous TCG publications as either the “Privacy CA” (PCA) or “Platform CA”. In an effort to separate the issues of privacy from those of attestation, that designation is replaced here with the term “Attestation CA” (ACA). The role and operation of the ACA is described in detail in section 3, below.

2.3 Original AIK Enrollment Process

As noted above, the AIK enrollment has previously been defined at a high level only. Nonetheless, this high-level description articulated requirements which have been realized within the TPM hardware in terms of TPM functions. Therefore, any enrollment protocol specification must take this into account, if it is to be useful for the large number of currently deployed TPM's.

The AIK certificate enrollment process is described in the TPM 1.1b specification (Section 9.3) [1], but the same text is not present in the TPM1.2 specifications [5] (even though the data structures remain present). Hence, before going further in defining an interoperable AIK enrollment protocol, we first describe the previously defined AIK enrollment process.

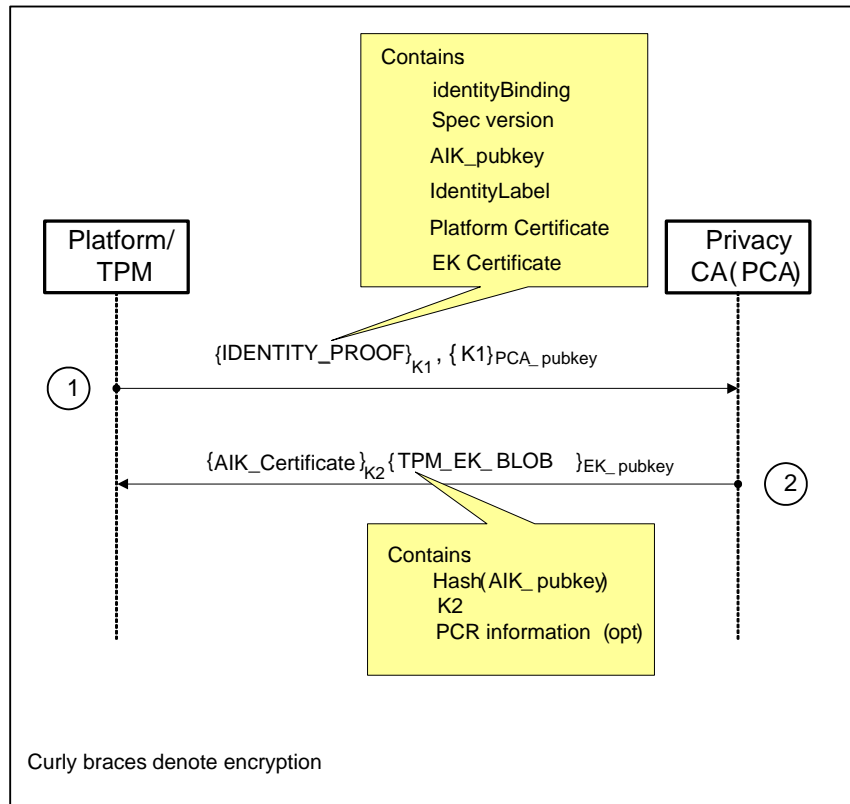


Figure 1 – Previously Defined AIK Enrollment Scheme

In the following we provide a general step-by-step description of the AIK certificate issuance process illustrated in Figure 1. The description is not an exact protocol flow definition. Rather, it enumerates the steps performed by a TPM-enabled platform and the ACA in order to issue and install an AIK certificate.

- **Step 1: Platform asks the TPM to create the AIK key pair.**
 - (a) The platform (or application software on the platform) issues to the TSS the *CollateIdentityRequest* command. In turn the TSS issues the *MakIdentity* command to the TPM. This results in the TPM generating a fresh AIK public key pair.

- (b) Within the **Makidentity** function the TPM creates the **IDENTITY_CONTENTS** structure containing the following items: (i) The structure version, (ii) TPM command ordinal, (iii) PrivCADigest label and (iv) AIK_pub_key.
- (c) The TPM signs **IDENTITY_CONTENTS** structure using the AIK_priv_key, with the resulting signature portion being referred to as the **identityBinding**.
- (d) The TPM outputs two (2) items as a result of the **Makidentity** command: AIK_pub_key and the **identityBinding**.

▪ **Step 2: TSS produces proof structure concerning the AIK**

- (a) Following from the previous step, the TSS creates the **IDENTITY_PROOF** structure. This structure consists of the following items:
 - (i) The **identityBinding** structure from Step 1(d). (Note: The **identityBinding** structure is the signature portion only over the **IDENTITY_CONTENTS** structure).
Note: It must be noted that the **identityBinding** structure is NOT cryptographic proof that the AIK is a TPM-resident key and that the AIK has been certified using the EK. It only demonstrates that *some* key pair exists.
 - (ii) The TPM spec version
 - (iii) The SubjectPublicKeyInfo (i.e. the AIK_pub_key)
 - (iv) The IdentityLabel
 - (v) EK certificate
 - (vi) Platform certificate
- (b) The TSS then generates a symmetric key K1 (local random number from the TPM) and encrypts the **IDENTITY_PROOF** structure using this symmetric key K1.
- (c) The TSS then encrypts key K1 using the public key of the ACA. This encryption using public-key of the Attestation CA is intended to limit disclosure of K1 to the ACA only.

The results of this step are two items: the encrypted **IDENTITY_PROOF** structure and the encrypted symmetric key K1. Encrypted **IDENTITY_PROOF** and encrypted K1 are bundled into an **IDENTITY_REQ** structure that includes identifiers for the symmetric and asymmetric algorithms used to encrypt the structures plus sizes of the encrypted structures.

▪ **Step 3: Platform sends AIK certificate request to the ACA.**

The platform (or application software on the platform) takes the **IDENTITY_REQ** resulting from the previous step, encrypts it, and sends it to the ACA.

▪ **Step 4: ACA verifies certificate request.**

Upon receiving the certificate request, the ACA must perform a number of verifications.

- (a) To get access to the AIK certificate request structure, ACA must first decrypt the key K1 using its ACA private key.
- (b) The ACA then uses K1 to decrypt the **IDENTITY_PROOF** structure.

- (c) The ACA must then recreate the **IDENTITY_CONTENTS** structure and verify that the signature (as represented by the received *identityBinding*) is correct. The ACA can perform the verification because it now has the items listed in Step 2 above and can assemble the same PrivCADigestLabel as was provided to the TPM.

As part of the verification, the ACA is expected to validate the received certificates (ie. EK and Platform Certificates). It is expected that the ACA will use standard X.509 certificate validation techniques, such as CRL checking [14] and/or querying the appropriate OCSP responders [15] to the issuer of the EK certificate (e.g. TPM manufacturer site).

▪ **Step 5: ACA issues a new AIK certificate.**

The ACA then creates a new AIK certificate, using (as the public key) the received AIK public key in the previous step. The ACA issues (signs) the new AIK certificate using its own AIK signing key.

▪ **Step 6: ACA encrypts the new AIK certificate.**

In this phase, the ACA must prepare the newly issued AIK certificate in a form recognizable by the TPM. As part of the **TPM_ActivateIdentity** command (Section 15.2 of [5]), the TPM expects input in the **TPM_EK_BLOB** or the (older spec version) **ASYM_CA_CONTENTS** structure.

The ACA performs the following tasks:

- (a) The ACA generates a random symmetric encryption key K2. This random K2 is unique for each AIK certificate request.
- (b) The ACA encrypts the new AIK certificate using key K2.
- (c) The ACA then creates either a **TPM_EK_BLOB** or **ASYM_CA_CONTENTS** (depending on the TPM version) structure which contains the following:
- (i) The hash of the AIK public key (namely the AIK public key as found in the original request).
 - (ii) The symmetric key K2.
 - (iii) Optional PCR information – for **TPM_EK_BLOB** only. The TPM checks to ensure that the TPM PCR's and locality are in the correct state as anticipated by the ACA to unlock K2.
- (d) The ACA encrypts the **TPM_EK_BLOB** or **ASYM_CA_CONTENTS** structure using the EK public key (as found in the EK certificate in the original request).

The purpose of the last step is to ensure that only the same requesting TPM will be the sole entity that can decrypt the newly issued AIK certificate, since only that TPM possesses the EK private key (which is a TPM-resident key).

▪ **Step 7: ACA delivers the new AIK certificate to the TPM on the Platform.**

The ACA then delivers the encrypted result (encrypted AIK certificate + either the blob or ASYM struct) to the requestor platform/TPM.

▪ **Step 8: Decryption of new AIK certificate by the TPM.**

Upon receiving the (encrypted) AIK certificate from the ACA, the platform must input the structure (either the blob or ASYM struct) (into the TPM and activate it using the TSS ***Tspi_TPM_ActivateIdentity*** command. This command decrypts the (encrypted) symmetric key K2 from the ACA using the EK-private-key (which resides only in the TPM) after ensuring an AIK with a matching pub key resides in the TPM. It then uses the symmetric key K2 to decrypt the AIK certificate.

2.4 Identity of a TPM and the AIK

Nominally, each TPM, once activated, has exactly one EK key pair, so that prior to activation, one TPM is indistinguishable from another. Once the EK pair is generated, it represents a unique identifier of a particular TPM hardware instance. As such, the EK and its certificate could be construed to be privacy sensitive. Thus, if protection of privacy is important to the TPM owner, then the EK and EK certificate should not be considered public, and should be available only to those entities which are trusted by the TPM owner.

By design, the EK is very limited in its uses. In particular, it can be used to decrypt the TPM_EK_BLOB, described in the enrollment protocol above. This means that an alternate key pair which can be used by the TPM to transact or communicate with the external world is desired. This alternate “identity” key pair is the *Attestation Identity Key* (AIK), which is an RSA key pair located within the TPM key hierarchy under the Storage Root Key (SRK).

An AIK is linked to an EK during AIK certificate enrollment, raising privacy concerns under some circumstances. In order to generally address the potential privacy issues arising from the use of an AIK key pair, the TCG adopts the following in its AIK design philosophy:

- *Multiple AIKs*: In order to reduce the possibility that an AIK can be used to identify a platform whose owner wishes to remain anonymous, a TPM is permitted to have any number of AIK key pairs and AIK certificates (subject to available resources). In theory, for each external entity with whom the TPM transacts, a separate AIK key pair and certificate could be used by the platform. In order to prevent services on the Internet from recognizing returning platforms, a unique AIK key pair *could* be created by the platform owner for each transaction.
- *Issuance of an AIK certificate by an Attestation CA*: A trusted third party (previously called the *Privacy CA* or *Platform CA*, referred to in this specification as the *Attestation CA*) performs the role of issuing AIK certificates to a given TPM-enabled platform. The core function of the ACA is to *vouch* for the TPM-enabled platform by issuing AIK certificates containing security assertions regarding the platform and the associated AIK. When a TPM-enabled platform requests an AIK certificate from the ACA, the platform must include a copy of the EK-certificate in the enrollment process. The ACA validates the EK-certificate, and may be expected to treat the EK-certificate as private information pertaining to the TPM. As such, the ACA may be trusted by the TPM Owner to never to reveal the EK certificate, or any information about the binding between the AIK and EK. The act of issuing an AIK certificate based on the received EK certificate provides some degree of “blinding” or indirection over the true EK certificate.

2.5 Purposes of an AIK Key pair

The AIK key pair is special purpose, in that it is only used for a small number of predefined operations. An AIK private key can only be used for two purposes:

- (1) *Signing internal TPM data*: For example, the TPM_Quote operation permits the TPM to reliably report the state of one or more of its internal registers (namely the *Platform Configuration Registers* or PCRs). The TPM_Quote operation can be also be used without specifying any registers. One possible input parameter to this operation is a cryptographically random value that is sourced externally to the TPM. When using the TPM_Quote function, the basic operation consists of the Verifier providing the Requestor with a challenge random nonce R. Upon receiving this nonce, the Requestor inputs the

nonce R into the TPM_Quote operation, essentially making R part of the output structure that is signed by the TPM using the AIK private key. It is possible to instruct the TPM to NOT include any PCRs in this computation, in which case what is verified is possession of the associated private key. The Verifier, who is assumed to be in possession of the Requestor's AIK certificate, can then verify the resulting (signed) TPM_Quote structure. Alternatively (or additionally), the TPM may sign its internal Tick Counter.

- (2) *Certifying general purpose RSA key pairs*: The TPM allows for the generation and use of general purpose RSA key pairs, such as those used for encryption and signing. A general purpose key is said to be a *Certified Key* (CK) when the private key is digitally signed by the AIK private key (itself a TPM-resident key). A TPM can create any number of CK key pairs (subject to available resources). As a further choice, when requesting the TPM to generate a CK key pair the keys can be denoted to be "certified migrateable" or "non-migrateable." Migration in this case means that the CK key pair can be moved to a different computer platform with a TPM under the control of a trusted entity, using a secure migration protocol that has been specified by the TCG [7]

Using the appropriate protocol an external entity can verify that a given CK key pair is TPM-resident. Provability of TPM-resident keys represents one of the attractive features of the TPM, since a TPM-protected key is more difficult to steal or modify compared to a software-protected key. The provability feature allows a software application on a platform with a TPM to transact with an external entity and prove (to that external entity) that the key it is using resides in the TPM and is operated by the TPM, thereby effecting an increased trust by that external entity.

When a CK public key is used within the standard X.509v3 certificate, a special extension called the *Subject Key Attestation Evidence* (SKAE) can be added to the certificate [16]. This extension allows a recipient of the certificate to obtain proof that the matching CK private key is a TPM-resident and TPM-persistent key that is operated by solely the TPM.

3 General Attestation CA Issues & Requirements

An AIK certificate asserts that the public AIK is associated with a valid TPM and a valid platform [4]. An AIK certificate nominally contains the following assertions:

- TPM properties: The AIK certificate contains an assertion by the Attestation CA that an AIK is controlled by a TPM and, furthermore, attests to the properties of the TPM implementation that holds the AIK.
- TPM specification conformance: The AIK certificate contains an assertion by the Attestation CA that the TPM bound to a platform conforms to TPM specifications for protected capabilities and shielded locations.
- Attestation CA evaluation process review: The AIK certificate implies an assertion by the Attestation CA that a reviewable evidentiary path exists to support the above assertions. For example, this could be proof that the Attestation CA maintains an audit trail of the certificate issuance process along with a reference to an audit trail maintained by the TPM manufacturer.

The Attestation CA is a pivotal element in AIK usage scenarios, and the relative security of AIK operations depends on the proper implementation, operation, and integrity of the ACA. Also, recall that an AIK certificate provides some degree of “blinding” or indirection over the EK certificate. In some use cases, it is intended to provide a measure of anonymity. In such cases, the primary goal of the AIK certificate is to attest that a TPM owns the AIK, and that the AIK is tied to valid EK and platform credentials (implying that it is TPM-resident), while simultaneously maintaining the relative anonymity of the platform with respect to the relying party. These are rather ambitious goals, and create a number of issues and requirements for the ACA. These are discussed further below.

3.1 Certificate Policy and Certification Practices

If AIKs are to be used interoperably, then somehow, the ACA must provide formal statements upon which potential enrollment domain participants can base expectations and trust. Typically, this is accomplished through publication of Certificate Policy (CP), and/or a Certification Practices Statements (CPS). While current X.509 standards don't explicitly mandate such documents, this particular specification requires some sort of structured statement. In the interest of flexibility, the exact form of this statement is not specified here. Nonetheless, for simplicity, we refer to this documentation below as “the CP/CPS”.

Ultimately the ACA will provide a policy statement that, paraphrasing [17], describes the applicability of issued certificates to a particular community or class of applications. In addition, the ACA should describe its issuance policies and operational practices, including privacy practices. It is on the basis of such statements that a relying party and enrollee invest trust in the ACA. In addition to the information defined in [17], the CP/CPS should articulate the following:

- What, if any, transactional records are maintained by the ACA, including a complete description of the content of those records. It is only through knowledge of this that the enrollee can fully evaluate the privacy (and other) risks associated with association with this ACA
- If the ACA maintains transactional records containing PII
 - What measures the ACA takes to protect those records; the enrollee must have some basis on which to evaluate the risks to PII
 - ACA procedure in case of PII compromise, so that enrollees know what to expect in such cases

Implementation Requirement IR.010: The ACA MUST provide formal statements describing enrollment policies, issuance policies, and operational practices. This statement MAY take the form of a CP and/or CPS, or it may take some other form. Regardless, in statements below this is referred to as the CP/CPS.

Implementation Requirement IR.020: The Authority Information Access (AIA) extension in the ACA certificate(s) MUST reference the CP/CPS.

Implementation Requirement IR.030: The CP/CPS MUST state whether or not the ACA maintains transactional records.

Implementation Requirement IR.040: If the ACA maintains transactional records, the CP/CPS MUST disclose the nature and content of these records.

Implementation Requirement IR.050: If transaction records contain PII, the CP/CPS MUST contain a description of measures taken to protect the confidentiality of those records.

Implementation Requirement IR.060: The CP/CPS MUST contain a description of ACA procedure in case of PII compromise.

In order to simplify the enrollment protocol, this specification calls for the ACA to choose which cryptographic algorithms it will support. In order for implementers to have some indication of which algorithms to implement, these must be specified somewhere. This will be included in the CP/CPS.

Implementation Requirement IR.070: The CP/CPS MUST indicate which cryptographic algorithms the ACA supports for enrollment.

3.2 Maintaining Privacy of EK and Platform Certificates

Much effort has gone into building privacy protections into TPMs and supporting protocols. At least one of the reasons for this is straightforward: Internet usage tracking is controversial, and some people desire a choice in the matter of what personally identifiable information makes its way into the hands of others. The TPM represents a potentially unique identifier for a given platform, and by extension, for its user(s). In order to address such concerns, TCG hardware and protocols have been designed to provide robust privacy protections.

On the other hand, as TPMs have become widely available, some useful applications have appeared for which privacy is not a central concern. For example, there are enterprise system and key management applications in which uniquely identifying the system is of critical importance, and the TPM potentially provides a robust basis for such identification. In these cases, the privacy protections mandated by the previous designs may create difficulties, and as a result, they may be ignored in part or in whole by implementers.

The ACA (previously called the Privacy CA, but now renamed to address our broadened usage) may or may not offer privacy guarantees, but if it does, then there are certain requirements we should impose on enrollment. The ACA has full visibility into the EK and Platform certificates, which may contain PII information. Hence, an ACA guaranteeing privacy services should never inappropriately reveal an EK or Platform certificate obtained through an authorized AIK certificate enrollment. Furthermore, it should protect AIK certificates in a similar fashion, since they may contain PII derived through the enrollment process.

The following requirements address privacy-specific enrollment concerns:

Implementation Requirement IR.080: an Attestation CA guaranteeing privacy MUST maintain as private all endpoint-provided certificates received as part of an authorized AIK certificate enrollment.

Implementation Requirement IR.090: disclosure of AIK certificates during the enrollment process (for example, to someone viewing the packets as they enter/leave the ACA) *might* allow correlation of multiple AIKs used by a platform, and/or may reveal PII that should be kept

confidential. Therefore, an Attestation CA guaranteeing privacy MUST NOT reveal an AIK certificate, except to the original AIK owner.

In addition to scenarios involving privacy concerns, there is at least one additional scenario in which the ACA must not reveal an AIK certificate, and that is the case in which the enrollment protocol does not include proof of possession of the EK. The previously defined AIK enrollment protocol (described above) provides for such a case. The reason for this is simple: that protocol relies on implicit proof of EK possession, and enforces this by encrypting the issued AIK certificate with a key that can only be decrypted by one holding the associated private EK. That is, the enrollee cannot obtain and use the issued AIK certificate unless it is able to decrypt the certificate.

Note that the security of this enrollment mechanism hinges on the fact that only the EK holder can decrypt the AIK certificate. If this certificate can be obtained in some other way, (e.g., if the ACA can be persuaded to release the AIK certificate through some alternate channel in unencrypted form), this protection may be circumvented:

- The attacker constructs an enrollment request for an arbitrary (non-AIK) key; the request includes valid EK/Platform certificates
- The attacker discards the enrollment reply (without access to the valid private EK, the reply is useless)
- The attacker obtains the AIK certificate through an alternative channel
- The attacker now controls a key which appears to be a valid AIK, *but which is not*

Implementation Requirement IR.100: disclosure of AIK certificates might allow access to an AIK certificate for which EK possession has not been proved (e.g., in case of a two-message enrollment exchange). Therefore, an Attestation CA supporting enrollment absent EK PoP MUST NOT reveal an AIK certificate, except to the original EK/AIK owner, and in such cases, the certificate MUST be in the EK-encrypted form provided during initial enrollment.

3.3 Absence of EK Certificate or Platform Certificate

An Attestation CA must address the case when an AIK certificate request is not accompanied by an EK certificate (i.e. is only accompanied by an EK public key) or a Platform Certificate (or both).

As defined in the TCG Credentials specification [4], an EK Credential asserts the following information:

- *Mandatory TPM specification compliance:* The TPM model correctly implements the protected capabilities and shielded locations according to a particular version of the TCG specification set, especially the protection of the private Endorsement Key (EK). The "TPM model" must be fully described by the following three data items: TPM manufacturer, TPM model, and TPM version number. The TPM model values are manufacturer-specific.
- *Optional TPM security assertions:* The EK Credential may include assertions that it meets various evaluation conformance criteria or that it was manufactured or initialized under certain specified conditions.

The absence of an EK-certificate denies the ACA crucial information regarding the TPM, including the TPM version, and other important security-relevant information captured in the Security Qualities field of the EK-certificate. Furthermore, without the EK certification, the ACA cannot be sure that the presented key is in fact an AIK, since it has no evidence that the key is associated with and resides in a valid TPM. This is fundamentally flawed, from a security perspective.

In view of this problem, an ACA has a number of practical options it can pursue with regards to the AIK certificate request:

- (a) *Reject the request.* The ACA in this case simply rejects any AIK certificate request not accompanied by valid EK/Platform certificates. This is the expected behavior in the general case.
- (b) *Rely on another (enveloping) signature on the request.* The ACA could rely on an additional layering of digital signatures applied to the certificate request. For example, a (non-TPM) public key certificate belonging to the Requestor could be used to provide confidentiality and integrity to the AIK certificate request (containing the AIK public key and the EK public key). This assumes underlying infrastructure and processes for platform registration leading to issuance of the signing certificate. Such processes are outside the scope of this effort.
- (c) *Use Security Qualities field or Reference Manifest.* The ACA could proceed with the issuance of an AIK certificate, but with a direct indication of the absence of the EK-certificate or Platform certificate. This direct indication can be expressed using a Security Qualities field (with the appropriate information in the field) or through a pointer to a Reference Manifest that expresses the same information. Note that this is only meaningful if the relying party knows how to interpret the field. Also note that without assumptions regarding the platform, ACA issuance policies, and integrity of the registration and AIK issuance process, AIK certificates issued in the absence of EK certificates and associated supporting evidence are typically not going to be very useful.
- (d) *Issue EK/Platform certificates:* in some cases, it may be feasible to have the ACA issue EK and platform certificates as part of the initial AIK enrollment process, but this requires out-band-evidence regarding provenance and integrity. For example, the IT department of an enterprise purchasing some number of systems containing uninitialized TPM's may wish to create an enrollment process in which EK, platform, and AIK certificates are issued all at once. In such cases, the IT department is essentially functioning as an OEM in a "late issuance" scenario [1].

Regardless of the approach used by an ACA to address this problem, it is important that an ACA clearly articulates its policies and practices within the appropriate CA policy/practices legal documentation. It is only on this basis that relying parties may realistically evaluate the resulting certificates.

3.4 Certificate Lifecycle Management

The ACA must provide a number of services relating to certificate lifecycle, as described below.

3.4.1 AIK Certificate Revocation

There are a number of reasons an AIK certificate might be revoked:

- Platform owner wishes to discard key
- Some portion of the EK-AIK evidentiary trail becomes invalid
 - EK or platform certificate issuing CA is compromised
 - EK or platform certificate is revoked
- It is somehow determined that the TPM, TBB, or platform has been compromised

Implementation Requirement IR.110: The ACA MUST provide for lifecycle management by (a) issuing short-lived certificates, the lifetime of which represents the revocation interval, (b) making available regular CRL updates which are easily retrievable by relying parties, or (c) making available an OCSF responder which is accessible to relying parties in real time.

Implementation Requirement IR.120: Any ACA which does not rely on short-lived certificates for lifecycle management MUST provide AIK credential revocation services which are accessible in real-time to platform owners.

Implementation Requirement IR.130: In cases where short-lived EK/platform certificates are not being used as part of a lifecycle management scheme (indeed, the vast majority of use cases would not rely on such measures), the ACA MUST provide revocation services which are accessible in real-time to TPM and platform manufacturers. This implies that the ACA must keep transaction records allowing it to revoke AIK certificates which depend on any particular TPM or platform manufacturer.

3.4.2 AIK Certificate Lifetime

While certificate lifetime limits are wholly within the discretion of the ACA, it is important to note that platforms wishing to utilize large numbers of AIKs to avoid correlation may place the ACA's revocation and lifecycle management infrastructure under significant load. One approach to this is to issue short-lived certificates which rapidly expire, and therefore do not require explicit revocation.

3.4.3 AIK Certificate Renewal

While some ACA's may rely on very long-lived AIK certificates to ease the lifecycle management burden, there may be deployments in which short-lived certificates will be more appropriate (as described above). In considering various scenarios, the question arises as to whether AIKs associated with expiring certificates should be discarded upon expiration, or if they should instead be re-used, with the associated certificates being renewed. The answer to this depends on a number of factors. While it is true that a new AIK could be generated if needed, there are practical reasons for avoiding this, particularly in cases involving short-lived certificates. A few examples that immediately come to mind are these:

- The AIK belongs to a power-constrained device, in which key generation takes a relatively long time, and/or in which it consumes significant amounts of power
- The platform is one of a large enterprise group, and the ACA maintains a database of enrolled AIKs. In such cases, failure to re-use AIKs would result in a database that practically grows without bound.

In cases of longer-lived certificates, there is also a chance that a certificate could be lost/corrupted. In such cases, it might be operationally simpler to simply re-enroll the same AIK, rather than to retrieve the issued certificate (which privacy-sensitive ACA's may not have saved). It seems clear that while some implementations may choose not to support AIK renewal, others will benefit from support.

Protocol Design Requirement DR.140: The enrollment protocol MUST NOT preclude AIK renewal.

3.4.4 Certificate Request Validation

In general, the Attestation CA is expected to provide robust validation of the AIK evidentiary chain. This includes the following:

- Validation of the EK CA certificate
- Validation of the EK certificate
- Proof of Possession (PoP) verification for the EK
- Validation of the platform certificate CA
- Validation of the Platform certificate
- Proof of Possession (PoP) verification for the AIK
- Proof of TPM residence for the AIK

The basis of trust in the AIK depends upon the proper execution of all of these steps. For example:

- If the EK CA certificate is not validated, there is no assurance that the EK resides in a TPM.
- If the EK certificate is not validated, there is no assurance that the public EK is valid, or corresponds to a private EK residing in a TPM from the claimed manufacturer.
- If (private) EK proof of possession is not validated, there is no assurance that the AIK is indeed a TPM-resident AIK.
- If the platform CA certificate is not validated, there is no assurance that the platform certificate is not a forgery
- If the platform certificate is not validated, there is no assurance that the TPM in which the EK/AIK reside is actually part of the platform the AIK is purportedly associated with.
- If AIK proof of possession does not occur, there is no guarantee that the enrollee actually possesses the AIK private key.

If any of these steps are omitted, the evidentiary chain is effectively broken, thereby voiding any guarantee that the key being certified is indeed an AIK residing within the purported TPM. This implies the following requirements:

Implementation Requirement IR.150: The ACA MUST provide strict EK certificate path validation as described in RFC 3280.

Implementation Requirement IR.160: The ACA MUST provide strict Platform certificate path validation as described in RFC 3280.

Implementation Requirement IR.170: The ACA MUST support requiring explicit Proof of Possession (PoP) for the associated EK as a prerequisite for AIK enrollment

Protocol Requirement DR.180: The ACA MUST require explicit Proof of Possession (PoP) for the AIK as a prerequisite for AIK enrollment

Protocol Design Requirement DR.190: The ACA MUST have the ability to verify that an AIK is TPM-resident prior to certificate issuance.

Protocol Design Requirement DR.200: The enrollment protocol MUST provide the ACA with the ability to cryptographically verify that the AIK resides in the TPM associated with EK and Platform Certificates presented by the platform during enrollment.

4 AIK Use Cases and Requirements

A high-level understanding of the use cases relating to AIKs is a critical precursor to a robust and comprehensive AIK enrollment protocol design. In the following sections, we first enumerate general AIK use cases, and from these, derive some common high-level requirements for AIK enrollment. In an appendix, we also examine reference usage scenarios in the following areas:

- Network Infrastructure Devices – this category includes network equipment such as switches, routers, wireless access points, wireless LAN controllers, and so on.
- Enterprise TPM Applications – Trusted Network Connect, machine/user authentication, storage security (e.g. HDD encryption)

These detailed use cases, while not essential to the enrollment protocol design, help to illustrate some of the unique features arising from differing enrollment environments and scenarios.

4.1 Entities and Roles

There are a number of entities which are present in all AIK use cases, but the roles taken on by each entity may vary depending, on particulars of the use case:

- Entities
 - TPM manufacturer – creates the TPM.
 - Platform Manufacturer – integrates the TPM into a product, such as a PC, network equipment, cell phone, etc.
 - TPM Owner – the entity who executes the TPM TakeOwnership command
 - Platform Owner – typically, the end user who purchases the platform, but may also be a service provider, employer, or other intermediate party.
 - End User – typically, the platform owner, but in cases where the platform is “loaned” or otherwise provided while maintaining an owner who is not the user, the end user is distinct from the platform owner.
 - EK CA – the certification authority which issues the EK certificate.
 - Platform Manufacturing (OEM) CA – the certification authority which issues the platform certificate.
 - Attestation (ACA) - the certification authority which issues the AIK certificate.
- Roles
 - Service Provider – integrators, software providers, or others who provide services of some sort (e.g. TNC, media distribution, HDD encryption management, etc) that use the TPM, AIK, etc., take on this role.
 - EK CA owner – This role may be filled by the TPM manufacturer, the platform manufacturer, the platform owner or a service provider.
 - Platform Manufacturing (OEM) CA owner – this role may be filled by the platform manufacturer, the platform owner, or a service provider.
 - Attestation CA (ACA) owner - this role may be filled by the platform manufacturer, the platform owner, or a service provider.

In each of the use cases described below, the associated entities and the roles they assume are described in detail. As it turns out, the per-scenario variations in the roles assumed by the entities directly influence the requirements for that use case.

4.2 Elements All Use Cases Share

In general, all AIK use cases will share some common elements:

- The Attestation CA (ACA): the ACA provides numerous certification authority services with respect to the AIK. From the platform perspective, in addition to relying on the ACA for certification, the ACA is trusted to honor the privacy policies agreed to between the platform owner and the ACA administrator. These may include such things as non-disclosure of PII, anonymity with respect to EK-AIK linkage, and so forth. From the perspective of relying parties, the ACA is expected to adhere to its published Certification Practice Statement (CPS). Typically, this includes a robust EK and platform certificate validation process, privacy guarantees, and perhaps other issuance controls and lifecycle management controls.
- ACA Repository Services: the ACA provides access to its CP, CPS, CRL's, and perhaps OCSP access; these are collectively referred to as ACA Repository Services.
- Platform: the platform contains a TPM and associated credentials, and requires AIK certification so that it can submit the certificate along with other data as evidence of the veracity of its assertions in various scenarios.
- Relying party: the relying party wishes to verify assertions made by the platform, and trusts the ACA to assist in creating a transitive chain of trust to assist in this.

It is evident that the ultimate common objective of the ACA, platform, and relying party is to support one of two general scenarios:

- To attest to the state of the platform (i.e. using the TPM Quote operation)
- To certify that a given RSA key is TPM-resident

These two scenarios are motivated by quite different, though potentially related, goals. For attestation, the foremost goal is to ascertain that the platform is indeed in a given state. One might infer, based on such attestation, that the platform will behave predictably as a result. In the second case, the goal is to ascertain that a key is indeed being used by a particular platform (the one containing the TPM which in turn contains the key). And of course, the two may be combined to support the inference that the key is being used by a particular platform which is in a particular state.

The crux of the matter in both cases is trust in the ACA: the relying party trusts the ACA to have "done its homework" prior to issuing the AIK certificate, to have verified that the platform contains a properly functioning TPM with all the expected properties. Based on a combination of this trust, and an understanding of and faith in the proper operation of the underlying TPM, the relying party then makes assumptions in support of achieving other goals. The platform owner, on the other hand, trusts the ACA to protect its PII, and to not provide this information to any third parties.

The potential use cases for platform attestation and key certification are far too numerous and broad to realistically enumerate here. The best we can do is to generalize with respect to these. However, it does make sense to try to capture some representative scenarios in order to gain some understanding of the basic requirements of a solution, and this is the goal of the following sections.

4.3 Strong Device Authentication Using a Certified Key

One of the benefits of current TPM design derives from support for Certified Keys (CKs), which are described above. There are many applications for which strong device authentication is desirable. In some applications, all related devices are within a single domain of control, but this is not always the case. For example, an organization may wish to strongly authenticate all devices joining the network using a protocol such as IEEE 802.1X [18], but that organization may or may not own all of the devices which require access.

In some cases, the organizational policy may limit network access to devices owned by the organization, but this is sometimes not the case. For example, an employee may have a personal mobile phone which supports IEEE 802.11 wireless access, and may wish to use this to access the organizational wireless network (e.g., for email/calendar synchronization). Alternatively, a business partner, or perhaps a consultant, may wish to connect a device not owned/controlled by the host organization, and achieve Internet access via the connection.

In the cases where the platform and relying parties fall entirely within one domain, the ACA may also be within that domain. In cases where the platform or the relying party are in different domains, the ACA may fall within one of the two domains, or it may be independently controlled by a (trusted) third party.

4.3.1 Common Elements of CK Authentication Scenarios

Essentially, in order to create a CK, the platform must have an AIK. Here is a simple overview of an idealized CK creation process:

- Device creates an AIK, and enrolls this AIK with an ACA (presumably, using the protocol defined by this AIK enrollment specification)
- Device creates the key pair which is to be certified
- Device certifies the key using the TPM-supplied API for this purpose, resulting in creation of the TPM_CERTIFY_INFO structure and the AIK signature over this structure
- The device creates the SKAE extension, and creates a Certificate Signing Request (CSR) for the CK which includes the SKAE
- The device submits the CSR to the ACA
- The ACA validates the CSR, and then issues the CK certificate containing the SKAE

Note that there are multiple options here. For example, the CK certificate may be issued by the ACA, but it may instead be issued by some alternative CA. Also, the SKAE may be authenticated by the CA prior to issuing the CK certificate, although the current SKAE specification does not mandate this behavior. However, the current SKAE specification *does* mandate SKAE validation by the relying party, which leads to very definite interoperability requirements.

4.3.2 Example Device Authentication Scenarios

Below is a sampling of potential real-world use cases for strong device authentication:

- Access to organizational LAN/WLAN (e.g. using IEEE 802.1X)
- Network device authentication (e.g., using IEEE 802.1AR)
- Hardware-based remote access solutions (e.g. personal VPN gateways, remote access points)

Clearly, there are use cases where the domain of control is singular, and others where domain boundaries are crossed. For example, while organizational LAN/WLAN access and remote access scenarios will typically be closed domains, there are guest access scenarios where strong device authentication might also be useful. Content distribution (e.g., movies, music) offers another obvious cross-domain application: the platform (perhaps a dedicated device such as an MP3 player) will frequently be owned by the platform user, while the content may or may not be provided by the device manufacturer. This cross-domain functionality has implications for the relationships between the platforms, ACAs, and relying parties, and for the associated operational requirements.

4.4 System Integrity Measurement and Monitoring

Like strong device authentication, there are also numerous applications for system integrity measurement and monitoring, and we may also segregate these in terms of intra vs. inter domain

usage. In TCG, this generally falls under the broad veil of Trusted Network Connect (TNC). There are numerous scenarios possible, including these:

- Organizational TNC: an organization requires user systems to be up to date with respect to Operating System (OS) patches, running an approved TNC client, and in compliance with organizational security policies in order to connect and remain connected to the organizational network. This can be a local or a cross-domain matter:
 - When managing systems it owns (e.g. employee laptops), this is a local matter
 - When providing guest access of some sort, this is a cross-domain matter. This use case is frequently supported by implementing a web-based captive portal via which a dynamic TNC client (e.g. ActiveX or Javascript) is downloaded to the guest system in order to facilitate a system scan
- Managed Security Service (MSS): a managed security service provider may provide system integrity measurement and monitoring services. These may be provided independently of and in addition to organizational TNC services.
- Network device management: as the number and complexity of network devices increases along with the mission critical applications depending on them, the integrity of these devices becomes increasingly important. While it is common to manage this problem today through periodic vulnerability scans, signed firmware, and network monitoring, system integrity monitoring solutions are beginning to appear on the market. It is only a matter of time before we see centralized management of these device monitoring agents. This may initially be deployed within local domains, but it is conceivable that some cross-domain mechanisms will eventually appear, e.g. between routing domains.
- Content Distribution, Digital Rights Management (DRM), license enforcement: maintaining strict control of the execution environment is a critical precursor to some DRM and licensing schemes. In such scenarios, the device manufacturer, device owner, and content owners typically represent 3 or more independent entities. In some cases, the relationship between these parties may even be somewhat adversarial, while in others, there may be alignment between some or all of the parties. This implies a need for both closed and cross domain enrollment, perhaps involving an independent trusted 3rd party ACA.

In general, integrity measurement services can be grouped in one of two categories: secure/trusted boot, or run-time attestation.

4.4.1 Secure/Trusted Boot

The terms “secure boot” and “trusted boot” have been previously defined [3] to identify approaches to system integrity verification during the initialization process. Generally speaking, “secure boot” means that the boot operation is interrupted and the device will not boot if something is amiss, whereas “trusted boot” means that the boot process is measured, and that these measurements, regardless of the final state of the system, cannot be successfully misrepresented by the device. Secure and trusted boot are very similar, with the primary differences being in whether or not the boot process is halted in case of unexpected measurements.

While it may be the case that a failed attempt at secure boot simply results in a “system halt”, the failure might also be somehow reported. When a report is issued, we might reasonably expect the report to contain an “attestation”, i.e. the output of a TPM QUOTE operation. This implies the use of an AIK, and also implies requirements in terms of supporting infrastructure.

4.4.1.1 Common Elements of Secure/Trusted Boot Scenarios

To better understand any specific requirements arising from this type of use case, it’s useful to walk through how we might actually implement this. The decision to stop the boot process (for

secure boot) might be implemented in a number of proprietary ways, so let's ignore that particular action for the moment, and instead focus on taking and reporting measurements.

In any trusted boot scenario, the following must occur:

- The system generates an AIK and obtains an AIK certificate from the ACA
 - Relying Parties (RPs) must trust the ACA to have validated the associated evidentiary trail, and that the public AIK resides in a valid TPM
- As the system initializes, Platform Configuration Registers (PCRs) are extended according to some previously agreed upon scheme
 - There must be a CRTM (e.g. the "bootloader") which implements this scheme, and perhaps other elements, depending on the initialization sequence. See [\[1\]](#) for further detail.
 - The RP need not understand the particulars of the integrity measurement scheme (e.g. what measurement goes into what PCR), but must know what to expect as output, i.e. RPs must have access to reference measurements against which to compare the device assertions
 - In terms of AIK enrollment/usage, the particulars of the integrity measurement scheme are out of scope, so we don't consider them further here.
- The RP must have an established trust relationship with the ACA
- The RP must have some way to retrieve the measurements from the device (e.g. TNC protocols)
 - In terms of AIK enrollment/usage, this is out of scope, so we don't consider this further here.
- Upon receipt of the measurements, the RP must validate them prior to interpretation. This implies path validation of the AIK certificate
 - RPs must have access to the AIK certificate chain leading to the trust anchor
 - RPs must have a way to obtain up-to-date AIK certificate chain status information (e.g., CRL retrieval or OCSP)

4.5 General AIK Credential Requirements Summary

While there are many potential environments and applications in which AIKs might be used, the primary use cases are limited to two broad classes: strong device authentication and system integrity management/monitoring. As illustrated in the general usages outlined above, there are cases where the principals (platform, ACA, and relying party) are all in the same domain, but there are also cases where they are not. This has concrete implications in terms of general requirements for the ACA as well as for AIK credentials. These are enumerated below.

4.5.1 Cross-domain Support

Since the relying party and platform are not guaranteed to be within the same domain of control in at least some of the use cases described above, it must be possible to use AIKs (and AIK certificates) in cross-domain applications. This implies variations in location and ownership of the ACA.

Implementation Requirement IR.210: It MUST be possible to use AIK credentials in cross-domain scenarios.

Following are some potential ACA roles, and associated requirements.

4.5.1.1 ACA as Independent Trusted Third Party

It must be possible to implement the ACA as an independent Trusted Third Party (TTP). The need for a generalized solution requires that no security assumptions be made regarding the intervening medium over which enrollment and other operations will occur. It is likely that at least some use cases, this will involve the Internet, or an otherwise hostile medium.

Implementation Requirement IR.220: It MUST be possible to implement the ACA as an independent TTP

In such scenarios, the platform may or may not have EK and platform credentials. If it does, the ACA must have a trust relationship with the associated CAs, as it will be making dependent assertions on that basis. If the platform has no EK/platform credentials, the ACA must have the ability to either issue such credentials (implying the ability to somehow validate any assertions contained therein), or the necessary processes and infrastructure to issue AIK certificates which either clearly indicate the lack of EK/platform certificates or can somehow make meaningful assertions despite the lack of manufacturing evidence.

It is not clear that AIK certificates of the latter type (i.e. those issued in the absence of EK/platform certificates and the associated trust relationships) are in any way useful for real-world applications. This is because the relying party has no assurance the AIK is indeed an AIK. Basically, the entire security foundation is missing. Therefore, there is no clear requirement to support AIK certificates that are not based on EK/platform certificates. As an alternative, the ACA may issue EK/platform certificates prior to issuing the AIK certificate, but this implies some sort of registration process which is clearly documented in the CPS of the ACA.

We should, however, distinguish between the absence of both EK and Platform certificates versus the absence of just the Platform Certificate. Presence of a Platform Certificate with no associated EK certificate is a degenerate case, as by definition, the Platform Certificate refers to the EK certificate, but there are real world examples today of systems containing TPM's for which the TPM manufacturer issued an EK certificate, but for which the platform manufacturer did not provide a Platform Certificate. It is possible to derive some level of assurance associated with such platforms. Hence, we should not rule out such scenarios. In such cases, the CPS of the ACA will indicate that it issues AIK certificates absent Platform certificates, and the fact that related AIK certificates do not carry the associated fields normally copied over from the Platform Certificates will imply the absence of the Platform certificates.

4.5.1.2 ACA provided by Platform Domain

In some scenarios, the ACA is a member of the same domain as the platform, e.g. the service is provided by the organization of which the platform is a member. If the relying party is a member of the same domain, it may trust the ACA implicitly, but here we mean to address cases where the relying party *is not* a member of the same domain, in which the relying party must choose to trust the ACA in some limited fashion. Enrollment in such cases may be conducted in a closed environment, entirely over a trusted medium, but it may also be conducted over the Internet (or other potentially hostile) medium.

Note that in these use cases, a platform starting out with no EK/platform credentials may or may not be tolerable, depending on the relationship between the relying party and the platform domain. If the relying party is willing to trust in the processes of the platform domain, it may be acceptable for the ACA to issue EK/platform certificates on which the AIK certificate is based, or alternatively, to simply make related assertions regarding the platform. For example, imagine the following scenario:

- An organization purchases a device containing an uninitialized TPM
- The Information Technology (IT) department unpacks the device, initializes it, takes ownership of the TPM, and generates the EK
- Using an organizational CA infrastructure, the IT worker optionally enrolls the device for EK and platform, certificates, and/or executes AIK enrollment of the platform.

In such cases, the basis of the assertions regarding the TPM and the platform are likely less reliable than they might be in cases where the EK/platform credentials were provided during manufacturing, but given the limited domain of AIK use, this may be acceptable. It depends upon the use case; the processes put in place by the platform domain administrator, and the willingness of the relying party to trust the ACA and associated processes. For scenarios involving post-manufacturing EK/Platform certificate issuance, it is important that the relying party has a clear indication of the provenance of the EK/platform certificates.

4.5.1.3 ACA provided by Relying Party Domain

In some scenarios, the ACA is a member of the same domain as the relying party, and this domain is distinct from that of the platform. In such cases, while the relying party may trust the ACA implicitly, the platform may choose to trust the ACA in a more limited fashion. For example, the platform owner may wish to minimize the amount of information disclosed to the ACA. Enrollment could conceivably occur over a trusted medium in some of these cases, but it seems much more likely that it would be over the Internet or other potentially hostile medium.

In cases where the platform has EK/platform credentials, the ACA must have a trust relationship with the issuing EK/platform CAs, and must have online access to timely information regarding the associated certificates (e.g. CRLs and/or OCSP responders). Otherwise, there is no basis for the ACA to believe that the AIK is truly an AIK, and any relying party would be well served to take note of this when presented with such an AIK certificate. In a similar vein, if the platform has no EK/Platform certificates, then the only way AIK enrollment makes sense is if the enrollment domain provides additional physical platform checks from which it derives assurance. This implies a localized enrollment process.

5 AIK Enrollment Requirements

We've seen above that AIK use cases have the following elements in common:

- Attestation CA (ACA): provides various certification authority services with respect to the AIK.
- ACA Repository Services: provides access to ACA CP, CPS, Certificate Revocation Lists (CRL's), and perhaps OCSP access
- Platform: contains a TPM and AIK.
- Relying party: wishes to verify assertions certified by the Platform with an AIK.

By extension, AIK enrollment use cases share these same elements. For simplicity, we refer to the ACA, Repository Services, Platform, and RP collectively below as "Enrollment Domain Participants" (EDPs).

In addition to having elements in common with AIK use cases, there is a need to support single and multi-domain variations on AIK enrollment:

- Single-domain enrollment, where the EDPs are all members of the same domain
 - Enterprise TPM management products; these may provide for initializing a TPM and issuing all/any needed certificates for operation
 - Turnkey network infrastructure device solutions; these are similar to the TPM management products, may involve provisioning devices with all needed certificates during manufacturing
 - Standards-based network infrastructure device solution deployed in a closed enterprise
 - Turn-key mobile phone solutions; like network infrastructure devices, this may involve provisioning devices with all needed certificates during manufacturing
- Multi-domain enrollment, where EDPs belong to 2 or 3 domains
 - ACA is TTP, Platform and Relying Party are independent
 - Example: multi-vendor media distribution applications (content protection/licensing)
 - ACA and RP belong to same domain, Platform is independent
 - Example: content distribution applications with ACA provided by content owner
 - ACA and Platform belong to same domain, RP is independent
 - Example: content distribution applications with mobile phone, where ACA and platform are considered part of phone providers domain, content provider (RP) is independent
 - ACA is TTP, platform and RP belong to same domain
 - ACA as a service

While the usage scenarios described above are somewhat vague, we have little choice but to make do with these as a basis for defining the protocol, because we have something of a chicken/egg problem:

- Without an enrollment protocol, AIK certificates are not widely deployed/used
- Without widely deployed AIK certificates, broad deployment of the associated use case scenarios is not possible

- Without broad deployment/usage, there isn't much information about how to solve the AIK enrollment requirements

Basically, we need to solve this problem in order to make it possible to broaden AIK (and by proxy, TPM) usage. In the following sections, we derive requirements for single and multi-domain enrollment based on the general descriptions above.

5.1 Single-domain Enrollment

The simplest AIK use cases involve a closed domain containing the ACA, Repository Services, Platform, and the Relying Party (all Enrollment Domain Participants, or EDP's). In these cases, a single organization or entity nominally controls all EDP's, and therefore, has full control over the enrollment environment and processes. In such cases, the organization has the ability to assess its own needs for confidentiality, availability, authentication, and so on, and to apply tools and mechanisms of its choice in order to achieve these. Hence, single-domain enrollment scenarios don't seem to impose any of their own unique security requirements on AIK enrollment.

On the other hand, single-domain enrollment scenarios do have many operational characteristics in common with multi-domain scenarios, and will benefit from many of the same general features we might derive from those requirements.

In terms of generalized requirements which apply to single and multi-domain enrollment, we have the following:

Protocol Design Requirement DR.230: The enrollment protocol **MUST NOT** preclude implementation of automated system registration/enrollment. Organizations may need to provision large numbers of AIK certificates, and if each and every enrollment operation requires human intervention, this will not scale well. The enrollment protocol must provide the ability to minimize human intervention when desired.

Protocol Design Requirement DR.240: The enrollment protocol **MUST NOT** preclude implementation of automatic certificate renewal. Organizations may need to provision large numbers of AIK certificates, and if each and every renewal requires human intervention, this will not scale well. While some deployment scenarios may favor such an approach, it is likely that many will not. One way lifecycle management may be addressed is by simply issuing short-lived certificates with implied revocation intervals corresponding to the validity interval. However, this approach entails relatively frequent certificate renewal, underscoring the need for an automatic renewal mechanism.

Protocol Design Requirement DR.250: Wherever possible, enrollment **SHOULD** use standardized protocols and building blocks that are available in commercial and open source products today. A low cost and/or freely available solution which fits easily into existing infrastructure and products will encounter the least amount of resistance to deployment. While it is possible that the enrollment requirements cannot be entirely met with existing off-the-shelf products today, the design **SHOULD** strive to minimize the changes required to adapt existing solutions.

Protocol Design Requirement DR.260: While it seems reasonable to expect that, at least in some cases, organizations might provide a secure enrollment environment, it also seems quite likely that in some cases they will not (see use cases in appendix for specific examples). Therefore, rather than relying on external security mechanisms, the enrollment protocol **MUST** provide support for integrated security mechanisms. In particular, the protocol **MUST** provide for strong mutual authentication, confidentiality, and integrity protection.

5.2 Multi-domain Enrollment

Complex use cases stem from multi-domain scenarios. The simplest of these involve having enrollment domain participants spread across two domains, while the most complex involve 3 separate domains (ACA as independent Trusted Third Party, or TTP). The generalized requirements derived for single-domain enrollment apply equally here, but multi-domain

enrollment entails additional requirements. Below, we first look at common requirements for multi-domain scenarios, and then treat each multi-domain variant individually to expose additional requirements.

5.2.1 Common Requirements for Multi-Domain Scenarios

Many of the requirements for multi-domain enrollment are the same, regardless of where the ACA resides. These common requirements are covered below.

5.2.1.1 Confidentiality of Enrollment Requests

In some cases, platform owners will wish to maintain confidentiality with respect to information contained in enrollment requests. In such cases, AIK enrollment information must not be disclosed to any third party other than those the platform owner explicitly wishes to share information with. This leads to a number of related requirements.

Protocol Design Requirement DR.270: The enrollment protocol MUST provide for confidentiality, e.g. by using a cryptographically secured communications channel.

Protocol Design Requirement DR.280: The ACA MUST publish its enrollment confidentiality policies in its CP/CPS, so that the privacy-sensitive enrollee has something on which to base an enrollment decision.

Protocol Design Requirement DR.290: The CP/CPS MUST be accessible to potential enrollees prior to and/or during the enrollment process. While the manner in which the enrollee evaluates the privacy (and other) policies and practices of the ACA is outside the scope of this specification, the ability for the enrollee to evaluate these prior to enrollment is a hard requirement.

5.2.1.2 Availability of Timely Certificate Status Information

All AIK use cases and enrollment scenarios require path validation, and to this end, the availability of timely certificate status information is critical. Hence, it is very important that up-to-date information always be accessible. One exception to this is when the ACA relies on short-lived certificates for lifecycle management, and does not support revocation within the associated validity interval. In cases where revocation is supported, repository services must always be available to relying parties. In cases where it is *not* supported, the CP/CPS must explicitly indicate this.

Implementation Requirement IR.310: If revocation is supported, ACA MUST maintain up to date Repository Services.

Implementation Requirement IR.320: If revocation is not supported, ACA MUST articulate this in CP/CPS.

5.2.1.3 Confidentiality of Certificate Status Information Requests

In the course of EK certificate path validation, the ACA may utilize some sort of online status check (e.g. OCSP, CRL retrieval). In order to maintain confidentiality, it is important that this activity not leak information about the enrollee. This implies that if online status checking is used for this purpose, a secure transport is employed for this purpose. Note that some information may still be leaked: for example, the fact that a particular OCSP responder is used may indicate the provenance of the EK certificate. However, use of a secure transport may help to minimize this leakage.

Implementation Requirement IR.330: If the ACA makes privacy guarantees regarding enrollment, this implies that the ACA MUST use secure transport (e.g., TLS) to protect path validation operations associated with enrollment.

5.2.1.4 Availability of Certification Policy

In order for relying parties and platform owners to enter into a trust relationship with the ACA, the Certificate Policy must be accessible to these parties.

Implementation Requirement IR.340: The ACA's CP/CPS MUST be available to platform owners and relying parties (e.g. posted to an accessible web site).

Protocol Design Requirement DR.345: The enrollment protocol SHOULD provide a method for requesting the ACA's CA certificate.

Implementation Requirement IR.350: The ACA's Issuance Certificate MUST have a reference to the CP/CPS

5.2.1.5 Availability of Certificate Practices Statement

In order for relying parties and platform owners to enter into a trust relationship with the ACA, the CP/CPS must be accessible to these parties. Further, the statement must be kept up to date and accurate, so that relying parties and platform owners can detect if/when it changes. Note that simply keeping it up to date and available is sufficient; there is no requirement that the ACA inform platform owners or relying parties of changes.

Implementation Requirement IR.360: The ACA CP/CPS SHOULD be available to platform owners and relying parties at all times (e.g. posted to an accessible web site).

Note that in some cases, the Certificate Policy and Certification Practices Statement are combined into one document. This specification is not impacted in any way by this, as both must be accessible to platform owners and relying parties at all times.

5.2.2 Independent ACA (Trusted Third Party)

When the ACA is independent of the platform owner and the Relying Party, the trust in the ACA must be explicit. This trust will be based on a number of factors, but in particular, will rely on the content of the CP/CPS. The ACA is required to publish a CP/CPS, but because a Relying Party may not have an established relationship with an ACA when an AIK certificate is presented, this use case imposes some new requirements in terms of timely access to the CP/CPS. These are described below.

5.2.2.1 Availability of CP/CPS

In order for Relying Parties and Platform Owners to enter into a trust relationship with the ACA, the CP/CPS must be accessible to these parties. This is covered by requirement IR.360.

5.2.3 ACA in Platform Domain

In this multi-domain scenario, the ACA and platform reside within one domain, while the relying party resides within another. In such cases, the platform may implicitly trust the ACA, but the relying party will not. From the relying party's perspective, the ACA and platform could collude to misrepresent platform state. However, the same could be said of scenarios involving a (corrupt) third-party ACA, and so this particular use case seems to add no new requirements not already implied.

5.2.4 ACA in Relying Party Domain

In this multi-domain scenario, the ACA and relying party reside within one domain, while the platform resides within another. In such cases, the relying party may implicitly trust the ACA, but the platform owner will not. From the platform owner's perspective, the ACA and relying party could collude to disclose information which the platform owner would prefer to remain private. However, the same could be said of scenarios involving an Independent ACA, and so this particular use case seems to add no new requirements not already implied.

SECTION II: Implementation

6 Privacy-Preserving AIK Certificate Enrollment

6.1 Background

The previously defined AIK enrollment protocol, described above in section 2.3, has a number of drawbacks. In this section we discuss these, and describe a protocol which remedies them.

By means of the data presented in the previously defined enrollment exchange, the ACA cannot verify that the AIK for which a credential is requested has indeed been generated by a TPM. Furthermore, the ACA cannot verify that the purported AIK belongs to the particular TPM owning the EK referenced in the enrollment request. There is no reliable connection between the information about EK, TPM and platform on one hand, and the AIK information on the other hand. In fact, prior to issuing the certificate, the ACA currently cannot verify that the key is indeed an AIK.

There are environments where this will not cause problems. For example, if an IT administrator controls the enrollment process and the ACA, correctness of AIK can potentially be verified by other (out of band) means. Also, enrollment can be conducted under highly controlled circumstances, minimizing the potential for various attacks.

However, in less strictly controlled environments, the fact that relationship between the TPM and AIK cannot be verified may cause very serious problems. For example, in such an environment, someone who gets hold of an EK and the corresponding credentials (for whatever reason) can generate an arbitrary RSA key pair (with a different TPM or entirely outside of any TPM) and request a credential for it from the ACA, and the ACA will happily provide the credential. This may be used to formulate a DoS attack, or for invalidating the TPM if the ACA's policy is to issue only a certain amount of AIK credentials to a certain TPM.

Also, while the certificate returned by the ACA is cryptographically protected by the EK, there may exist some alternative means for the enrollee to obtain a copy of the issued AIK certificate (e.g. by accessing an ACA database through some unexpected channel). In this case, the entire enrollment process is subverted: a certificate is issued for a key which may not be an AIK, and which may not be related in any way to the EK used in the enrollment transaction.

Given the current state of the art in cryptography, and the tools available to the CA and potential enrollees, these vulnerabilities may be remedied in a fairly straightforward manner. Hence, they are unacceptable, and should be addressed. A protocol which accomplishes this is described below.

6.2 A Privacy-Preserving AIK Enrollment Protocol: Summary

Following is a high-level overview of a proposed enrollment scheme which addresses the AIK-TPM binding problem referenced above while still meeting the privacy requirements of the original AIK enrollment design. This overview steers clear of the enrollment transport protocol (e.g., CMC) discussion in an effort to highlight essential aspects of AIK enrollment. In subsequent sections, we detail one instantiation of this enrollment protocol using CMC.

In this proposal, the main aim is for the TPM to prove to the ACA that the AIK private key is TPM-resident, and in fact, is resident in the TPM that houses the EK associated with the request. This requires that the ACA trusts the assertions in the EK certificate (and in particular, that the private EK is TPM-resident), and that the TPM owner provide proof of possession of the private EK. Recall that in prior TCG specifications, this proof of possession is weakly implicit (i.e. the enrollee is expected to decrypt the issued AIK certificate using its private EK), but this is never verified by the ACA. Hence, an attacker who obtains the AIK certificate by other means is able to completely

subvert this weak protection, and obtain a seemingly valid AIK certificate for key which is not an AIK.

In the following proposal, possession of the EK private key is explicitly proved by demonstration of the ability to decrypt and return an ACA-chosen value (R) using the EK private key, and this proof is verified prior to certification of the AIK. Possession of the corresponding AIK private key is proved by signing the *identityBinding* structure. Hence, this protocol explicitly proves possession of both the EK and AIK private keys, and also proves (based on transitive trust relating to the EK) that the AIK is TPM-resident. At the same time, the additional evidence is provided using symmetric cryptography, so it does not constitute cryptographic evidence to a third party that the AIK belongs to a TPM with a particular EK, because it could have been provided by either the ACA or the TPM. This maintains the privacy properties of the original AIK enrollment protocol.

6.3 The Privacy-Preserving Protocol: A Detailed Look

- **STEP-1a: Platform asks the TPM to create the AIK key pair.**
 - (e) The platform (or application software on the platform) issues to the TSS the ***CollateIdentityRequest*** command. In turn the TSS issues the ***MakIdentity*** command to the TPM. This results in the TPM generating a fresh AIK public key pair.
 - (f) Within the ***MakIdentity*** function the TPM creates the **IDENTITY_CONTENTS** structure containing the following items: (i) The structure version, (ii) TPM command ordinal, (iii) PrivCADigest label and (iv) AIK_pub_key.
 - (g) The TPM signs **IDENTITY_CONTENTS** structure using the AIK_priv_key, with the resulting signature portion being referred to as the ***identityBinding***.
 - (h) The TPM outputs two (2) items as a result of the ***MakIdentity*** command: AIK_pub_key and the ***identityBinding***.

- **STEP-1b: TSS produces proof structure concerning the AIK**
 - (d) Following from the previous step, the TSS creates the **IDENTITY_PROOF** structure. This structure consists of the following items:
 - (vii) The ***identityBinding*** structure from Step 1(d). (Note: The ***identityBinding*** structure is the signature portion only over the **IDENTITY_CONTENTS** structure).

Note: It must be noted that the ***identityBinding*** structure is NOT cryptographic proof that the AIK is a TPM-resident key and that the AIK has been certified using the EK. It only proves that the platform has the ability to construct and sign such a structure using *some* key.

 - (viii) The TPM spec version
 - (ix) The SubjectPublicKeyInfo (i.e. the AIK_pub_key)
 - (x) The IdentityLabel
 - (xi) EK certificate
 - (xii) Platform certificate

- (e) The TSS then generates a symmetric key K1 (local random number from the TPM) and encrypts the **IDENTITY_PROOF** structure using this symmetric key K1.

- (f) The TSS then encrypts key K1 using the public key of the ACA using a standard key wrapping algorithm.

The results of this step are two items: the encrypted **IDENTITY_PROOF** structure and the encrypted symmetric key K1. Encrypted **IDENTITY_PROOF** and encrypted K1 are bundled into an **IDENTITY_REQ** structure that includes identifiers for the symmetric and asymmetric algorithms used to encrypt the structures plus sizes of the encrypted structures.

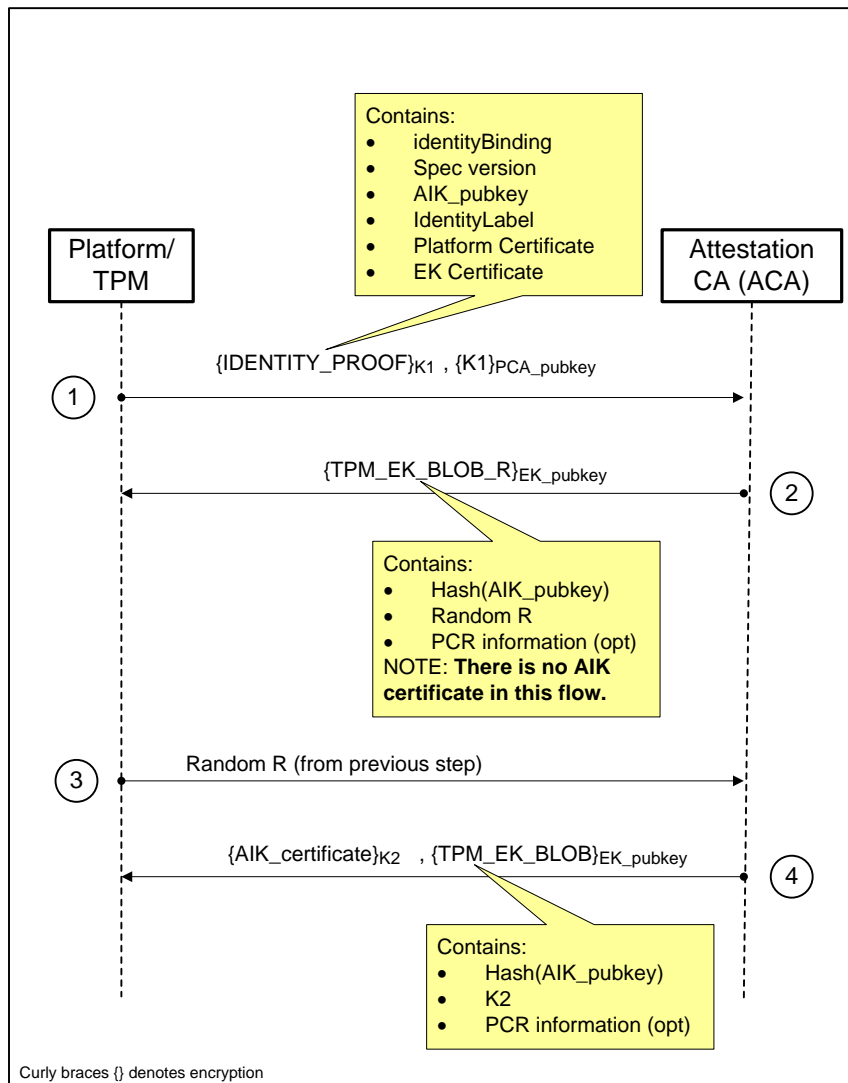


Figure 2: A Privacy-Preserving AIK Enrollment Protocol

▪ **STEP-1c: Platform sends AIK certificate request to the ACA.**

The platform (or application software on the platform) takes the **IDENTITY_REQ** resulting from the previous step and sends it to the ACA.

It is important to note that it is the *signature* over the **IDENTITY_CONTENTS** structure (as represented by **identityBinding** structure) which is sent to the ACA. The

IDENTITY_CONTENTS structure itself is NOT sent, as the ACA has all information needed to reconstruct it in order to validate the signature.

NOTE: The TPM1.1b and TPM1.2 specifications do not describe the precise messaging format used for the certificate request from the Platform to the ACA. This will be addressed below.

This is Message-1 in Figure 2.

- **STEP-2a: ACA verifies certificate request.**

Upon receiving the certificate request, the ACA must perform a number of verifications.

- (a) To get access to the AIK certificate request structure, ACA must first decrypt the key K1, using its ACA private key.
- (b) The ACA then uses K1 to decrypt the **IDENTITY_PROOF** structure.
- (c) The ACA must then recreate the **IDENTITY_CONTENTS** structure and verify that the signature (as represented by the received *identityBinding*) is correct. The ACA can perform the verification because it now has the items listed in Step 2 above and can calculate the same PrivCADigestLabel as was provided to the TPM.

As part of the verification, the ACA is expected to validate the received certificates (i.e. EK Certificate, Platform Certificate). It is expected that the ACA will use standard X.509 certificate validation techniques, such as CRL checking [14] and querying the appropriate OCSP responders [15] to the issuer of the EK-certificate (e.g. TPM manufacturer site).

NOTE: Although at this point the ACA has a copy of the EK-certificate of the requesting TPM, the ACA has no way of knowing that the matching AIK_private key is truly resident in that very same TPM. That is, there is no cryptographic linkage between the EK key pair and the AIK key pair at this stage. The enrollment protocol must remedy this.

- **STEP-2b: ACA creates a challenge R**

The ACA performs the following tasks:

- (a) The ACA generates a random R. This random R is unique for each AIK certificate request.
- (b) The ACA then creates **TPM_EK_BLOB_R** structure which contains the following:
 1. The hash of the AIK public key (namely the AIK public key as found in the original request).
 2. The random R.
 3. Optional PCR information.
- (c) The ACA encrypts the **TPM_EK_BLOB_R** structure using the EK public key (as found in the EK certificate in the original request).

- **STEP-2c: ACA sends the TPM_EK_BLOB_R structure to the TPM on the Platform.**

This is Message-2 in Figure 2.

- **STEP-3a: The TPM decrypts TPM_EK_BLOB_R structure**

This step consists of loading the AIK into the TPM and performing TPM_ActivateIdentity using the blob containing the ACA's random number. The TPM verifies that the public key contained in the blob corresponds to the loaded AIK and that this key is indeed an AIK, and then returns the ACA's random number.

- **STEP-3b: The Platform/TPM returns random R to the ACA**

This random number R is returned to the ACA and serves as a proof that the TPM holding the EK indeed controls the AIK for which a credential is requested. Thus the random number provides the binding of TPM and AIK.

This is Message-3 in Figure 2.

- **STEP-4a: ACA issues a new AIK certificate.**

The ACA then creates a new AIK certificate, using (as the public key) the received AIK public key in the previous step. The ACA issues (signs) the new AIK certificate using its own CA private key.

- **STEP-4b: ACA encrypts the new AIK certificate.**

In this phase, the ACA must prepare the newly issued AIK certificate in a form recognizable by the TPM. As part of the TPM_ActivateIdentity command (Section 15.2 of [5]), the TPM expects input in the TPM_EK_BLOB or the (older spec version) ASYM_CA_CONTENTS structure.

The ACA performs the following tasks:

- (e) The ACA generates a random symmetric encryption key K2. This random K2 is unique for each AIK certificate request.
- (f) The ACA encrypts the new AIK certificate using key K2.
- (g) The ACA then creates a TPM_EK_BLOB or ASYM_CA_CONTENTS structure which contains the following:
 - (i) The hash of the AIK public key (namely the AIK public key as found in the original request).
 - (ii) The symmetric key K2.
 - (iii) Optional PCR information – for TPM_EK_BLOB only. The TPM checks to ensure that the TPM PCRs and locality are in the correct state as anticipated by the ACA to unlock K2.
- (h) The ACA encrypts the TPM_EK_BLOB or ASYM_CA_CONTENTS structure using the EK public key (as found in the EK certificate in the original request).

The purpose of the last step is to ensure that only the same requesting TPM will be the sole entity that can decrypt the newly issued AIK certificate, since only that TPM possesses the EK private key (which is a TPM-resident key).

- **STEP-4c: ACA delivers the new AIK certificate to the TPM on the Platform.**

The ACA then delivers the encrypted result to the requestor platform/TPM.

This is Message-4 in Figure 2.

- **STEP-5: Decryption of new AIK certificate by the TPM.**

Upon receiving the (encrypted) AIK certificate from the ACA, the platform must input the structure into the TPM and activate it using the TSS *Tspi_TPM_ActivateIdentity* command. This command decrypts the (encrypted) symmetric key K2 from the ACA using the EK-private-key (which resides only in the TPM) after ensuring an AIK with a matching pub key resides in the TPM. It then uses the symmetric key K2 to decrypt the AIK certificate.

Note that this protocol does not confirm that the platform successfully decrypted K2, and therefore the issued AIK certificate. Since proof of possession has been verified for both the EK and AIK prior to creation of the AIK certificate, this is not a security concern. The certificate is encrypted with K2 only to ensure that it remains confidential to anyone other than the correctly configured platform containing the associated EK. For cases in which this might present some sort of operational issues, the CMC implementation specified below provides for an optional acknowledgement message from the platform to the ACA.

7 AIK Enrollment Over CMC

In this section we give a brief overview of CMC [8][9] followed by a description of how the Privacy-Preserving AIK enrollment Protocol described above may be implemented over CMC. Note that this section is very terse in its description of CMC, assuming that the reader either has the necessary background, or will read the referenced documents for additional information.

7.1 CMC Overview

Certificate Management Messages Over CMS (CMC) is a comprehensive, standardized certificate management protocol. While every effort is made to align this proposal with the protocol requirements laid out in [8,9], in some cases we impose restrictions or deviations which might be considered non-compliant with the standard. We do this only when strictly necessary in order to (a) maintain compatibility with existing TCG specifications, and/or (b) support a higher level of assurance consistent with TCG applications.

CMC supports 3 high-level enrollment exchange types, each composed of PKI Requests and PKI Responses: exchanges using the Simple PKI Request/Response, exchanges using the Full PKI Request and a Simple PKI Response, and exchanges using the Full PKI Request/Response. CMC also supports numerous other functions, but we leave them aside for now. PKI Requests used for enrollment are in part formed using either the PKCS #10 [11] or CRMF structure. Following is a brief summary of the supported request types:

- Simple PKI Request: a bare PKCS #10 request with no CMS elements
- Full PKI Request: one or more PKCS #10, CRMF, or Other Request Message structures wrapped in a CMS encapsulation as part of a PKIData content-type element.

PKI responses are based on the CMS [10] SignedData element. Following is a brief summary of the supported response types:

- Simple PKI Response: SignedData containing only certificates (e.g. the requested certificate, and the associated trust anchor chain)
- Full PKI Response: a PKIResponse wrapped in a SignedData.

The Simple PKI Request is suitable for straightforward enrollment scenarios involving signed PKCS #10 structures, and in general, is used in a single round-trip exchange. The Full PKI Request, on the other hand, is potentially very rich and complex. Note that in general, use of the Simple PKI Request is not suitable for AIK enrollment, for multiple reasons. Most notably, it cannot be used because of restrictions on AIK and EK usage: we require proof of possession for both the AIK and the EK, and there is no obvious way to provide for this using a simple PKCS #10 request.

We do note that alternative AIK enrollment schemes which depend on an additional platform signing key, and other transitive trust measures, could potentially be implemented using the Simple PKI Request. However, specification of such schemes is beyond the scope of this document, and we instead rely on the Full PKI Request/Response. Below, we describe some key features of the Full PKI Request/Response model before going on to describe how the AIK enrollment protocol described here may be implemented using a subset of these features.

7.1.1 Full PKI Request/Response

Following is a high-level overview of the content of the Full PKI Request and Response as defined for CMC. This is for illustrative purposes, and is simplified accordingly. For complete details, see [8].

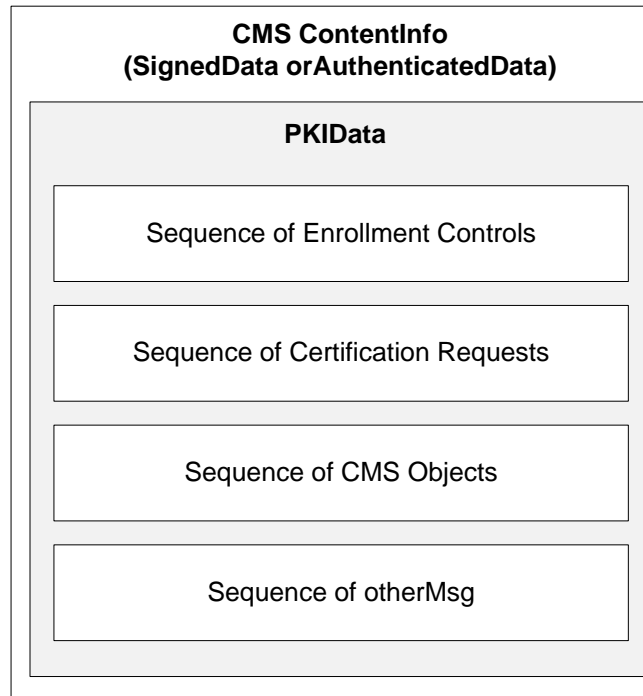


Figure 3 - Full PKI Request

Note that the request contains the following (in the PKIData structure):

- Enrollment control sequence
 - A sequence of zero or more enrollment controls as defined in CMC
- Certification request sequence
 - A sequence of zero or more certification requests based on PKCS #10, CRMF, or Other Request formats.
- CMS object sequence
 - A sequence of zero or more CMS message objects. The four content types used are AuthenticatedData, Data, EnvelopedData, and SignedData (defined in [7]).
- Other message sequence
 - A sequence of zero or more arbitrary data objects which are referred to by one or more controls (allows controls to use large amounts of data without having to embed the data directly in the controls).

The following illustrates the full PKI response:

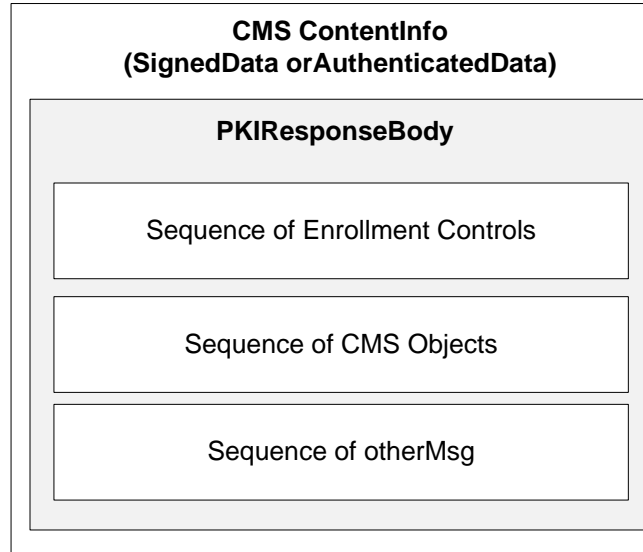


Figure 4 - Full PKI Response

The response contains the following in the PKI Response Body:

- Enrollment control sequence
 - A sequence of zero or more enrollment controls as defined in CMC
- CMS object sequence
 - A sequence of zero or more CMS message objects. The four content types used are AuthenticatedData, Data, EnvelopedData, and SignedData (defined in [7]).
- Other message sequence
 - A sequence of zero or more arbitrary data objects which are referred to by one or more controls (allows controls to use large amounts of data without having to embed the data directly in the controls).

7.1.2 CMC Proof Of Possession (POP) Controls

CMC supports POP for encryption-only keys either through proving knowledge of a shared secret, or via use of the Encrypted and Decrypted POP controls. Since we require explicit proof of possession for the associated private Endorsement Key, we must rely on the latter.

For encryption-only keys, there are 4 distinct steps required for explicit POP:

1. Client tells server about public component of encryption key pair, typically as part of a certification request transaction
2. Server sends client a POP challenge, encrypted with the public encryption key
3. Client decrypts POP challenge with corresponding private key and sends proof to server
4. Server validates proof and continues processing certification request

CMC defines two relevant POP-related controls: one for the encrypted “challenge”, sent from the server to the client, and one for the “proof”, sent from the client to the server.

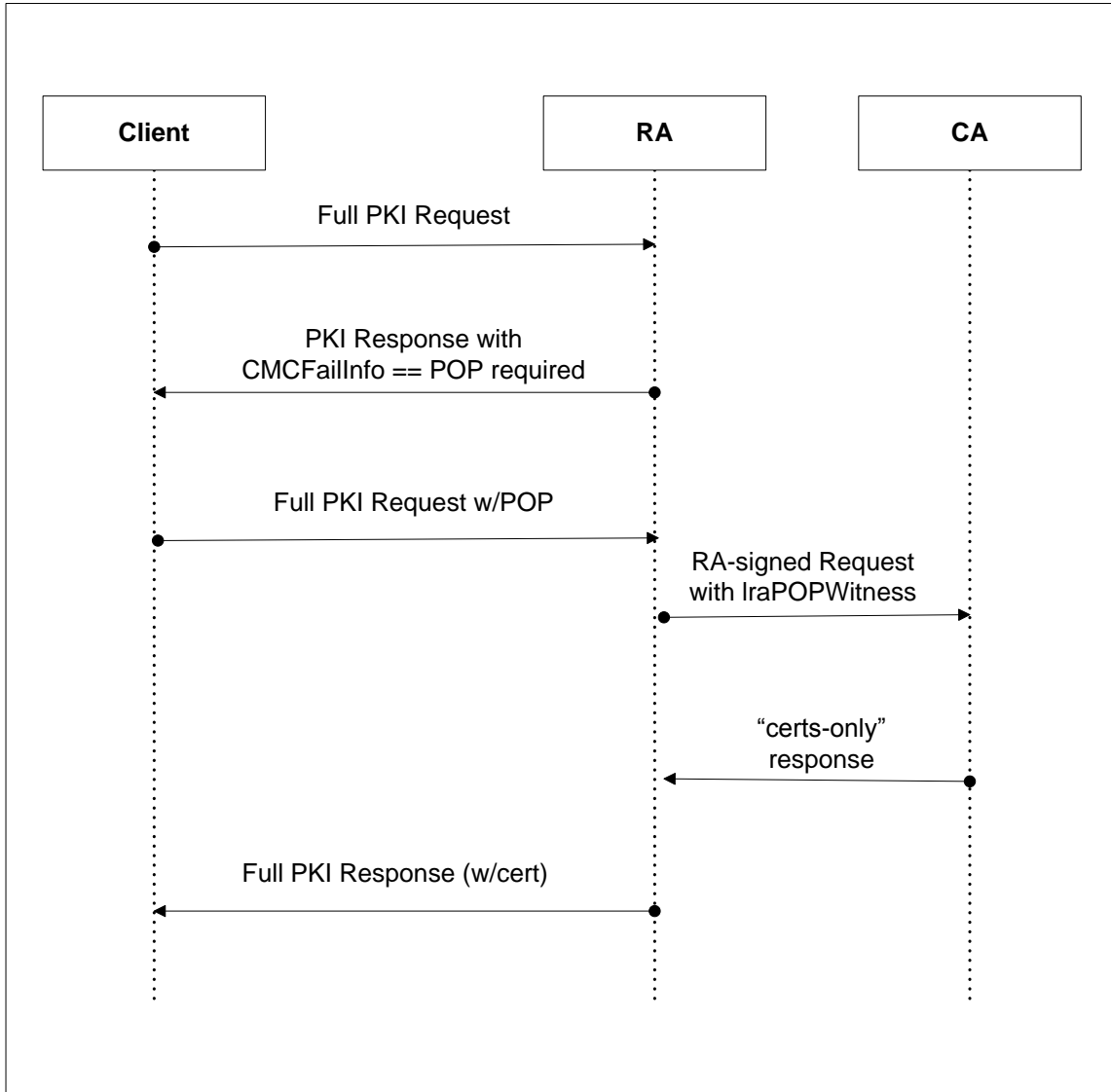
The Encrypted POP control is used to send the encrypted challenge from the server to the client as part of the PKIResponse. Note that it is assumed that the message sent in Step 1 above is a Full PKI Request and that the response in step 2 is a Full PKI Response including a CMCFailInfo specifying that a POP is explicitly required, and providing the POP challenge in the encryptedPOP control.

The encrypted POP algorithm works as follows (as described in [8]):

1. The server generates the POP Proof Value and associates it with the request. This value is typically derived from a random value to protect against replay.
2. The server returns the Encrypted POP Control to the client with the following fields set:
 - request - the original certification request (e.g. a PKCS10 request)
 - cms - EnvelopedData, the encapsulated content type being id-data and the content being the POP Proof Value
 - thePOPAId - identifies the algorithm to be used in computing the return POP value
 - witnessAlgID - identifies the hash algorithm used on POP Proof Value to create the field witness,
 - witness - the hashed value of POP Proof Value.
3. The client (using its private key) decrypts the cms field to obtain the POP Proof Value and verifies it by computing a hash of this (using the witnessAlgID) and comparing it against the witness value
4. The client creates the Decrypted POP control as part of a new PKIData. The fields in the DecryptedPOP are:
 - bodyPartID - refers to the certificationRequest in the new PKI request
 - thePOPAId - identifies the algorithm to be used in computing the return POP value,
 - thePOP - contains the possession proof
5. The client resubmits the full PKI request, this time including the DecryptedPOP control
6. The server then recomputes the POP value and compares it to the value of the POP. If the values do not match, the server will not issue the certificate. Otherwise, the server issues the certificate and returns it in a full PKI response message.

7.1.3 Putting it together: CMC Enrollment with POP

Following is a high-level walk through of CMC enrollment implementing POP. Note that this is very similar to the privacy-preserving protocol described above:



In this scenario, the client forwards the Full PKI Request to the RA. Keep in mind that the RA may co-reside with the CA in a single platform, and may simply represent a logical module of the CA application. Alternatively, it may reside on a physically separate system. Furthermore, there may be additional RA's situated between the one illustrated here and the CA, and perhaps even between the one pictured here and the client, but for simplicity, we ignore this.

In any event, the RA pictured above rejects the client's first attempt, notifying the client that POP is required. The client decodes the POP challenge (and locally validates it), and then resubmits the request with the POP proof. The RA validates the POP proof, and then forwards the request to the CA. The CA returns the certificate(s) to the RA, and the RA forwards the certificate(s) (and any additional data and/or CMC controls) to the client.

7.2 CMC Authentication Considerations

CMC supports two methods for integrity verification and data origin authentication: use of a Message Authentication Code (MAC) computed based on a shared secret, and use of the CMS SignedData encapsulation. In many cases, platforms enrolling for AIK certificates will not have a certified key suitable for use in authenticating AIK enrollment transactions, so we must support platform authentication based on a pre-provisioned shared-secret. In such cases, while using the

shared key symmetrically might be simplest, it is significantly more secure if the RA authenticates using a certified signing key, so that is the approach specified here.

In cases where the platform has no suitable public key for authentication (the default enrollment scenario in this specification), asymmetric authentication is used. That is, PKI requests **MUST** be wrapped in a CMS AuthenticatedData (authenticated with the shared secret), and PKI responses **MUST** be wrapped in a CMS SignedData (signed by the RA). In cases where the platform has a suitable public key, CMS SignedData **MAY** be used for PKI requests.

It is **REQUIRED** that the enrolling platform be securely provisioned out of band with the shared secret. It is **RECOMMENDED** that the enrolling platform also be securely provisioned with all trust anchors and keys needed to complete the enrollment transaction with the RA and ACA (described more fully below) prior to commencement of the enrollment process. If provisioning the trust anchors along with the shared secret is problematic, then it is **RECOMMENDED** that they be retrieved from the RA, in an exchange which is authenticated by the shared secret. The precise manner in which this is accomplished is out of scope for this specification, and implementers are admonished to recognize that the relative security of the entire enrollment process depends on secure implementation of this procedure.

7.3 Implementation Preliminaries

While section 7.1 outlines a CMC-based enrollment process from a high level, there are a number of important nuances and subtleties that must be addressed in order to properly implement privacy-preserving AIK enrollment using CMC:

1. The CA will sign the AIK certificate, implying existence of a CA signing key; however, the RA must be able to decrypt the key (K1) used to encrypt the CMS EnvelopedData. A signing key **MUST NOT** be used for this purpose. Hence, the RA **MUST** have its own (encryption-only) key for this purpose.
2. If the RA is distinct from the CA, then the RA request on behalf of the client **MAY** need to be signed by the RA, i.e. the RA will require a signing key which the CA trusts. Also, as noted above, the RA requires a signing key in order to support CMS SignedData encapsulation for data sent from the RA to the client (and this **MAY** be the same key used to sign requests for the CA). Since there may be other RA's, we will refer to the RA pictured above as the Attestation RA, or ARA.
3. Since CMC requires that Full PKI Requests be encapsulated in either a SignedData or AuthenticatedData, either an acceptable signing key or a shared secret is required in order for the platform to initiate a CMC enrollment transaction. This specification has provisions for both, but support for a shared secret **MUST** be provided, while support for platform signing keys **MAY** be provided. This is discussed further in section 7.3, below.
4. In order to complete the transaction, the platform must have the ARA's (public) encryption key (to encrypt K1, the key used to protect the CMS EnvelopedData), and must also have the RA's public signing key in order to authenticate the CMS SignedData encapsulation. This specification assumes that these keys are provisioned along with trust anchors prior to commencement of AIK enrollment.

For AIK enrollment, we must support the following use cases:

- UC.enroll.1: the platform is pre-provisioned with a shared secret and the required trust anchors and RA public keys.
- UC.enroll.2 the platform has a valid signing key that the RA will recognize, and has been provisioned with the required trust anchors and RA public keys.

Support for other approaches is out of scope.

7.3.1 Data Security and Encapsulation

In order to meet the confidentiality requirements outlined in previous sections, this specification requires the use of CMS EnvelopedData as defined in [10]. Since the enrollment protocol already defines a content encryption key (K1), we can simply use this key for encrypting the data. Briefly, here is an overview of the EnvelopedData encapsulation, along with some implementation-related commentary:

```
EnvelopedData ::= SEQUENCE {
    version CMSVersion,
    originatorInfo [0] IMPLICIT OriginatorInfo OPTIONAL,
    recipientInfos RecipientInfos,
    encryptedContentInfo EncryptedContentInfo,
    unprotectedAttrs [1] IMPLICIT UnprotectedAttributes OPTIONAL }
```

In general, OriginatorInfo is optional, and may contain certificates and/or CRLs. For this specification, OriginatorInfo MUST NOT be present.

RecipientInfo serves to relate the manner in which key distribution occurs to the identity of the receiver. There are 4 variants defined. For our purposes, the platform will generate K1 and wrap it with the public key of the ARA. For this purpose, we use the KeyTransRecipientInfo variant, defined as follows:

```
KeyTransRecipientInfo ::= SEQUENCE {
    version CMSVersion, -- always set to 0 or 2
    rid RecipientIdentifier,
    keyEncryptionAlgorithm KeyEncryptionAlgorithmIdentifier,
    encryptedKey EncryptedKey }
```

This specification requires KeyTransRecipientInfo MUST be present, and that the CMSVersion MUST be set to 2. The RecipientIdentifier MUST be populated with the SubjectKeyIdentifier (which will be present in the ARA's encryption key certificate). For KeyEncryptionAlgorithmIdentifier, the RSAES-OAEP [13] algorithm MUST be supported.

The platform is responsible for generating K1. Since the platform is enrolling a TPM which contains a hardware random number generator, it is assumed that the platform is capable of producing random numbers of sufficient cryptographic strength for use as K1. The precise manner of generation does not impact interoperability, so it is not specified here. However, implementers are admonished to note that predictable keys may result in a compromise of the enrollment protocol.

Since K1 will be also be used for securing packets from the ARA to the client (who may not have a public encryption key), we need some alternative for RecipientInfo when sent from the ARA to the client. That is, the client will frequently have no means for unwrapping an encrypted content key. Since the client already knows the value of K1, there is no need to transmit the key, but CMS requires that this structure be present in the message – therefore, to comply with CMC, and to ensure that no unauthorized data is inadvertently leaked via this channel, we simply included the same RecipientInfo in the ARA-to-platform messages that the platform previously constructed and sent to the ARA. The platform SHOULD maintain a local copy of K1, and verify that the packet from the ACA contains the same value as was sent in the enrollment request.

```
EncryptedContentInfo ::= SEQUENCE {
    contentType ContentType,
    contentEncryptionAlgorithm ContentEncryptionAlgorithmIdentifier,
    encryptedContent [0] IMPLICIT EncryptedContent OPTIONAL }
```

The following ContentEncryptionAlgorithmIdentifiers MUST be supported:

```
id-aes128-CBC OBJECT IDENTIFIER ::= { aes 2 }
id-aes192-CBC OBJECT IDENTIFIER ::= { aes 22 }
id-aes256-CBC OBJECT IDENTIFIER ::= { aes 42 }
```

Additional ContentEncryptionAlgorithmIdentifiers MAY be supported. The ACA defines any additional algorithms it supports by indicating supported algorithms in its Certification Practices Statement (CPS).

7.4 The CMC Implementation

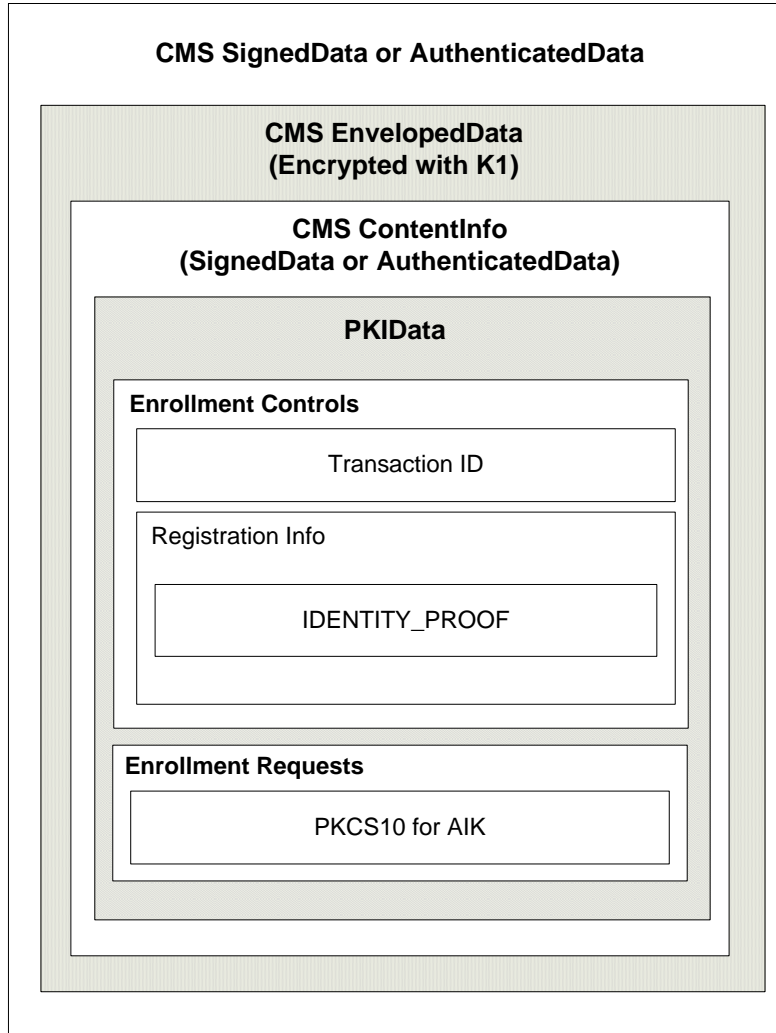
Here we assume that a shared secret has been provisioned to both the RA and the platform, and that the platform has any necessary trust anchors installed. Further, we assume the RA has both an encryption and a signing key, and that the CA has only a signing key, and that the platform is in possession of the RA signing and encryption keys. Following is a brief synopsis of how enrollment proceeds:

- Platform constructs CMC Full PKI Request, sends to ARA/ACA
- ARA constructs unique POP value, sends CMC Full PKI Response message containing POP challenge which is encrypted with the PubEK
- Platform decrypts POP challenge with PrivEK, validates it, adds proof to CMC Full PKI Request and resubmits to RA/CA
- RA/CA validates platform proof, issues certificate, returns it to the platform in a CMC Full PKI Response

A more detailed description of each step in enrollment proceeds is covered in the following sections.

7.4.1 Creation of the Initial Full PKI Request

Following is an illustration of the initial Full PKI Request for AIK enrollment:



This encapsulation is constructed according to the recommendations in [8]. Note that the innermost structure is a PKIData. This is wrapped in CMS AuthenticatedData (assuming a shared secret is employed for platform authentication), which is in turn wrapped in EnvelopedData, with the entire bundle again wrapped in AuthenticatedData. In the following sub-sections, we describe the content of the PKIData structure.

7.4.1.1 Transaction ID

This integer value is generated by the platform as a transaction reference value which allows the platform to correlate replies with requests. It is not interpreted by the ARA or ACA. The platform MAY choose any value which is convenient.

7.4.1.2 Registration Info

The Registration Info MUST hold a single regInfo control which encodes the encrypted IDENTITY_PROOF. The regInfo element is defined as an OCTET STRING; this contains the binary representation of the IDENTITY_PROOF. While the original enrollment protocol specified that the IDENTITY_PROOF structure be encrypted with K1, this would be redundant here, as the entire CMS EnvelopedData is encrypted. Hence, we do not separately encrypt IDENTITY_PROOF here.

7.4.1.3 PKCS10 Request

The CMC reqSequence MUST be present. It MUST include the AIK Certificate request in PKCS10 format. Since the PrivAIK cannot be used to sign this request, the signature element MUST hold id-alg-noSignature {id-pkix id-alg(6) 2} in place of the signature. For more information on use of id-alg-noSignature, see [8]. Implementations providing EK/Platform certificate enrollment in the same step MAY include additional PKCS10 requests for this purpose.

7.4.2 Creation of the Initial Full PKI Response

When the ARA receives the PKI request, it MUST authenticate the message. For a detailed discussion, see [10]. Following this, the ARA MUST unwrap the EnvelopedData, and authenticate the enclosed PKIData.

If message authentication fails, the ARA response is a matter of policy. In environments in which denial of service is not a concern, the ARA SHOULD send a response. In this case, the response SHOULD be as defined below for unrecognized encryption algorithm identifier, except that the CMCFailInfo for this case is authDataFail (13).

Assuming the message validation succeeds, the ARA must attempt to unwrap the EnvelopedData. If the ContentEncryptionAlgorithmIdentifier is not supported/recognized, the ARA MUST construct a Full PKI Response, and this MUST be authenticated with the ARA's signing key. In the controls section, the RA MUST encode the following controls (as described in section 3.2.1.3.4 of [8]):

- Extended CMC Status Info Control (id-cmc-statusInfoV2) with the following fields:
 - Status: failed (2)
 - otherInfo: CMCFailInfo
 - CMCFailInfo: badMessageCheck (1)

Assuming message decryption succeeds, the ARA examines the enrollment controls section of the request. Finding no decrypted POP control in the request, the ARA infers that this is the first message. The ARA extracts the EK public key and the AIK from the IDENTITY_PROOF structure. If any error is encountered in parsing the enrollment request, the ARA constructs and sends a Full PKI Response, which will be authenticated with the ARA's signing key. In the controls section, the RA MUST encode the CMC Status Info Control as in the example above. The ARA MAY send the value "badRequest" with no further information about the failure, but if possible, the CMCFailInfo value which most closely identifies the problem SHOULD be sent. The ARA MAY also include ExtendedFailureInfo to further identify the problem.

If the message passes all ARA checks, then the ARA must now construct the POP challenge value (R), which will be encrypted, and only accessible to the enrollee if it has the appropriate private key. The manner in which the challenge value is constructed is implementation-dependent, and out of scope for this specification. The purpose of the challenge value is to ensure, to a high degree of probability, that the platform has the private EK. The primary threats to this mechanism would consist in a malicious platform being able to predict the value of R somehow. This might be accomplished if either the method of generating R is weak, or if an R value from a previous protocol run (for which the platform knows the correct value) could be re-used in a later run. Hence, construction of R MUST ensure that

- It is not practical to guess it in advance
- The odds of colliding R values is vanishingly small (minimizing likelihood of re-usability, given a valid, earlier value).

If the ARA wishes to remain stateless, then it MAY implement a challenge generation mechanism that depends on the enrolling platform somehow, and which allows stateless reconstruction of the challenge when the platform submits a challenge response. Alternatively, the ARA MAY choose to maintain a record of outstanding challenges. This is implementation dependent.

Regardless of how the ARA generates the challenge R, the RA constructs the encrypted TPM_EK_BLOB as follows:

$$\{\text{Hash}(\text{PubAIK}) \mid R \mid \text{optional PCR info}\}_{\text{EK_pub}}$$

Now, the ARA constructs a Full PKI Response, which will be authenticated with the ARA's signing key. In the controls section, the RA MUST encode the following controls:

- Extended CMC Status Info Control (id-cmc-statusInfoV2) with the following fields:
 - Status: failed (2)
 - otherInfo: CMCFailInfo
 - CMCFailInfo: popRequired (8)
- The encrypted POP control (described below)

The RA must construct the Encrypted POP control, which has the following ASN.1 definition:

```
EncryptedPOP ::= SEQUENCE {
    request          TaggedRequest,
    cms              ContentInfo,
    thePOPAlgID     AlgorithmIdentifier,
    witnessAlgID    AlgorithmIdentifier,
    witness          OCTET STRING
}
```

As noted above, the POP proof value is R. The RA constructs the Encrypted POP control, where the following fields MUST be set as specified below:

- request – contains the original PKCS10-encoded AIK certificate request from the platform
- cms – EnvelopedData with a content type of id-data and the content being {TPM_EK_BLOB}_{EK_pub}
- thePOPAlgID – identifies the encryption algorithm for encrypting R prior to returning it in the follow up request
- witnessAlgID – identifies the hash algorithm to be used in computing the return POP value
- witness – the hashed value of R

The PKI response is then returned to the platform. Note that the RA/CA need not maintain local state; this is an implementation decision.

7.4.3 Creation of the Full PKI Request Including POP

Upon receiving the initial PKI Response, the platform first validates the message using the shared secret. Invalid messages MUST be discarded, and SHOULD be logged.

Assuming the message validation succeeds, the platform then extracts the encrypted POP control, yielding {TPM_EK_BLOB}_{EK_pub}.

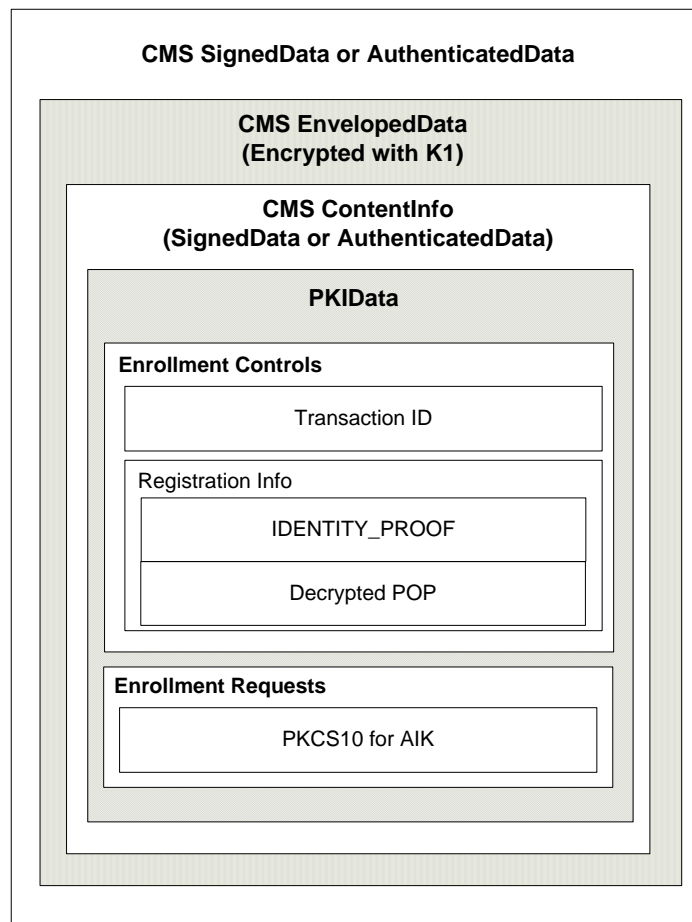
This value is then decrypted through a call to the TSS Activate Identity function. Following this call, the TSS will return R. The platform, by applying to R the hash algorithm defined by thePOPAlgID in the encrypted POP control, will derive the witness value. This MUST be compared with the witness value in the encrypted POP control; if these do not match, the transaction has failed, so the platform SHOULD log this event and MUST discard the message.

Assuming the locally computed witness value matches the one contained in the PKI Response message, the platform constructs a new PKI request, this time adding the Decrypted POP control

to the enrollment controls. That is, the request is exactly the same as the initial request, except that the Decrypted POP control is added. The Decrypted POP control has the following ASN.1 definition:

```
DecryptedPOP ::= SEQUENCE {
    bodyPartID      BodyPartID,
    thePOPAlgID     AlgorithmIdentifier,
    thePOP           OCTET STRING
}
```

The BodyPartID MUST refer to the AIK PKCS10 enrollment request contained in the new Full PKI Request message. The AlgorithmIdentifier value MUST be copied directly from the PKI response message. The OCTET STRING (thePOP) MUST contain the transformed R. This message is illustrated below:



It is possible for an attacker to capture this message and replay it again and again. Rather than adding complexity to the enrollment protocol in an effort to mitigate this, it is RECOMMENDED that the ACA implement some appropriate means of anti-replay detection. For example, the ACA has considerable latitude in formulation of the POP value. One simple replay mitigation mechanism consists of constructing the POP as a concatenation of R and a timestamp. If a request is received for which the timestamp is considered to be out of date (e.g., it is some number of “ticks” behind the current timestamp), then the request could be discarded. Alternatively, the ACA could maintain some state associated with the ongoing POP transaction,

and discard this when either the transaction completes, or some time interval elapses. Since this implementation choice need not influence interoperability, we leave the design of this mechanism to the ACA implementer.

This updated Full PKI Request is forwarded by the platform to the RA/CA.

7.4.4 Creation of the Final Full PKI Response

When the ARA receives the FULL PKI request, it MUST authenticate the message. For a detailed discussion, see [10]. Following this, the ARA MUST unwrap the EnvelopedData, and authenticate the enclosed PKIData.

If message authentication fails, the ARA response is a matter of policy. In environments in which denial of service is not a concern, the ARA SHOULD send a full PKI response. Otherwise, the platform may continue to send erroneous requests. In this case, the response SHOULD be as defined below for unrecognized encryption algorithm identifier, except that the CMCFailInfo for this case is authDataFail (13).

Assuming the message validation succeeds, the ARA must attempt to unwrap the EnvelopedData. If the ContentEncryptionAlgorithmIdentifier is not supported/recognized, the ARA MUST construct a Full PKI Response, and this MUST be authenticated with the ARA's signing key. In the controls section, the RA MUST encode the following controls (as described in section 3.2.1.3.4 of [8]):

- Extended CMC Status Info Control (id-cmc-statusInfoV2) with the following fields:
 - Status: failed (2)
 - otherInfo: CMCFailInfo
 - CMCFailInfo: badMessageCheck (1)

Assuming the message is successfully decrypted, the ARA examines the controls, and finding the Decrypted POP control, extracts the PubAIK from the IDENTITY_PROOF structure. Using this, the RA re-computes R as previously specified above.

Using R, the ARA computes the transformation by applying the algorithm specified by thePOPAlgID to R, and then compares this value to thePOP (contained in the Decrypted POP control). If these values match, the platform has proved possession of the PrivEK. If these do not match, the request MUST be discarded, and SHOULD be logged.

The ARA MUST confirm the presence of the EK and Platform certificates. As a matter of policy, an ACA MAY permit enrollment absent the Platform certificate, but the EK certificate MUST be present. If a required certificate is not present, the ARA MUST discard the request, and SHOULD construct a Full PKI Response, and this MUST be authenticated with the ARA's signing key. In the controls section, the RA MUST encode the following controls (as described in section 3.2.1.3.4 of [8]):

- Extended CMC Status Info Control (id-cmc-statusInfoV2) with the following fields:
 - Status: failed (2)
 - otherInfo: CMCFailInfo
 - CMCFailInfo: badRequest (2)

Otherwise, the ARA MUST perform path validation on the EK and platform certificates as defined in RFC 3280. If path validation fails, the ARA MUST discard the request, and SHOULD construct a Full PKI response (as defined above) with CMCFailInfo set to badIdentity (7). If path validation succeeds, the ARA has obtained assurance that the certificate request is indeed for a TPM-resident AIK. If path validation fails due to temporary unavailability of repository services, CMCFailInfo MUST be set to tryLater (12).

The RA must now transform the request into one that is acceptable to the CA. This is accomplished by marking the controls which have already been processed, adding the IraPOPWitness control which encapsulates the platform's PKCS10 request, and signing this with the RA signing key. For a detailed explanation of this process, see [8].

The resulting, modified request is forwarded to the ACA. The ACA validates the ARA signature on the request, fills in any additional certificate fields and/or adds any required extensions based on its policy (NOTE: ARA could do this as well), and creates/signs the resulting certificate. This is returned to the ARA.

Alternatively, the ARA may be implemented as a module of ACA. In this case, the PKCS10 request MAY be passed directly to the ACA, with no further encapsulation, RA signature, etc. That is, the ARA MAY encapsulate all knowledge of the CMC protocol API, and the ACA MAY trust the ARA implicitly. This is an implementation detail which falls beyond the scope of this specification.

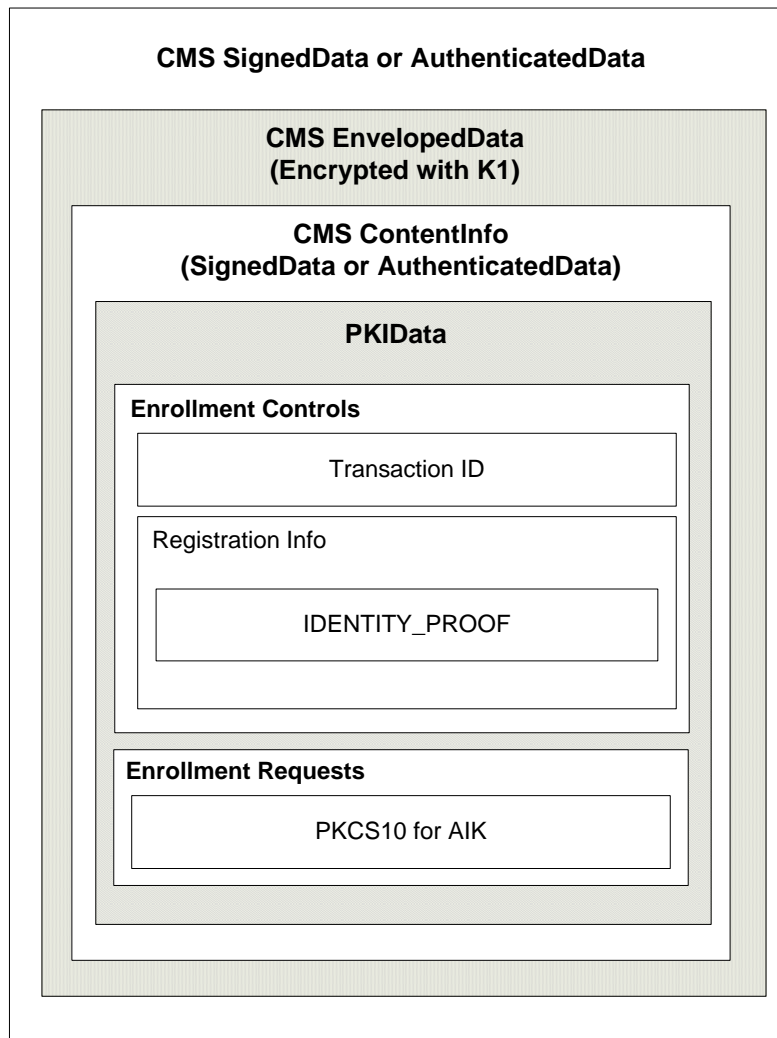
Regardless of which approach is taken, the ACA will produce either the AIK certificate, or an error message. The ARA, upon receiving the response from the ACA, MUST create a Full PKI response which will be returned to the platform. To maintain confidentiality, the RA MUST encapsulate the PKIData in a CMS EnvelopedData and encrypts this with K2. K2, in turn, is encrypted with the PubEK extracted from the request, and the entire response is wrapped in CMS AuthenticatedData, and signed with the public key of the ARA. This message is returned to the platform.

8 Simple AIK Enrollment Over CMC

In some cases, it may be desirable to implement a simplified enrollment method by eliminating the explicit EK possession proofs. This is straightforward, and is described below. Note that this is essentially the protocol described above without the proof of possession exchange. That is, rather than replying to the initial PKI request with PoP challenge, the ACA replies with the full PKI response containing the AIK certificate.

8.1 Creation of the Initial Full PKI Request

Following is an illustration of the initial Full PKI Request for simplified AIK enrollment:



This encapsulation is constructed according to the recommendations in [8]. Note that the innermost structure is a PKIData. This is wrapped in CMS AuthenticatedData (assuming a shared secret is employed for platform authentication), which is in turn wrapped in EnvelopedData, with the entire bundle again wrapped in AuthenticatedData. In the following sub-sections, we describe the content of the PKIData structure.

8.1.1 Transaction ID

This integer value is generated by the platform as a transaction reference value which allows the platform to correlate replies with requests. It is not interpreted by the ARA or ACA. The platform MAY choose any value which is convenient.

8.1.2 Registration Info

This holds a single regInfo control which encodes the encrypted IDENTITY_PROOF. The regInfo element is defined as an OCTET STRING; this contains the binary representation of the IDENTITY_PROOF. While the original enrollment protocol specified that the IDENTITY_PROOF structure be encrypted with K1, this would be redundant here, as the entire CMS EnvelopedData is encrypted. Hence, we do not separately encrypt IDENTITY_PROOF here.

8.1.3 PKCS10 Request

This value holds the AIK Certificate request in PKCS10 format. Since the PrivAIK cannot be used to sign this request, the signature element MUST hold id-alg-noSignature {id-pkix id-alg(6) 2} in place of the signature. For more information on use of id-alg-noSignature, see [8].

8.2 Creation of the Full PKI Response

The ARA, upon receiving the PKI request, MUST validate the message using the shared secret. If message authentication fails, the ARA response is a matter of policy. In environments in which denial of service is not a concern, the ARA SHOULD send a response. In this case, the response MUST be as defined below for unrecognized encryption algorithm identifier, except that the CMCFailInfo for this case is authDataFail (13).

Assuming the message validation succeeds, the ARA must attempt to unwrap the EnvelopedData. If the ContentEncryptionAlgorithmIdentifier is not supported/recognized, the ARA MUST construct a Full PKI Response, and this MUST be authenticated with the ARA's signing key. In the controls section, the RA MUST encode the following controls (as described in section 3.2.1.3.4 of [8]):

- Extended CMC Status Info Control (id-cmc-statusInfoV2) with the following fields:
 - Status: failed (2)
 - otherInfo: CMCFailInfo
 - CMCFailInfo: badMessageCheck (1)

Assuming message decryption succeeds, the ARA examines the enrollment controls section of the request.

The ARA extracts the IDENTITY_PROOF from the RegistrationInfo control, and extracts the EK public key and the AIK from the IDENTITY_PROOF structure. If any error is encountered in parsing the enrollment request, it is a matter of local policy as to whether a reply is sent or not. If a reply is to be sent, then the ARA MUST construct and send a Full PKI Response, which MUST be authenticated with the ARA's signing key. In the controls section, the RA MUST encode the CMC Status Info Control as in the example above. The ARA MAY send the value "badRequest" with no further information about the failure, but if possible, the CMCFailInfo value which most closely identifies the problem SHOULD be sent. The ARA MAY also include ExtendedFailureInfo to further identify the problem.

The RA must now transform the request into one that is acceptable to the CA. This may be accomplished by marking the controls which have already been processed, adding the IraPOPWitness control which encapsulates the platform's PKCS10 request, and signing this with the RA signing key. For a detailed explanation of this process, see [8].

The resulting, modified request is forwarded to the ACA. The ACA validates the ARA signature on the request, fills in any additional certificate fields and/or adds any required extensions based on

its policy (NOTE: ARA could do this as well), and creates/signs the resulting certificate. This is returned to the ARA.

Alternatively, the ARA could be implemented as a module of ACA. In this case, the PKCS10 request could be passed directly to the ACA, with no further encapsulation, RA signature, etc. That is, the ARA could encapsulate all knowledge of the CMC protocol API, and the ACA may trust the ARA implicitly. This is an implementation detail which falls beyond the scope of this specification.

Regardless of which approach is taken, the ACA will produce either the AIK certificate, or an error message. The ARA, upon receiving the response from the ACA, **MUST** create a Full PKI response which will be returned to the platform. To maintain confidentiality, the RA **MUST** generate a cryptographically random value for K2. The RA **MUST** encapsulate the PKIData in a CMS EnvelopedData and encrypt this with K2. K2, in turn, **MUST** be encrypted with the PubEK extracted from the request, and the entire response **MUST** be wrapped in CMS AuthenticatedData, and signed with the public key of the ARA. This message is returned to the platform.

9 Security Considerations

Multiple use cases for AIK's and AIK enrollment are possible, and while they have many overlapping requirements, there are unique, use-case-specific requirements, some of which are security-related. Security considerations are frequently dependent on the use case in question, but ideally, the AIK enrollment protocol design will provide mitigating controls for the threats encountered in any case, and utilization of those controls will be implementation dependent. Hence, the main goal of this section is to understand what threats may exist in realistic deployments of all sorts, and what security requirements these threats impose on the enrollment protocol.

Since at least one of the use cases described above (Trusted Third Party ACA) suggests a potential for Internet-based enrollment, it is expedient to assume a worst-case threat model for all use cases, and then to note those areas where security controls may be relaxed in the specific use cases when appropriate. Hence, we adopt a pessimistic form of the "Internet Threat Model", further degrading it by assuming that, in addition to the potential existence of threats *between* the communicating endpoints, one of the endpoints may be hostile.

9.1 Adversary Capabilities

In closed environments, there may be controls in place that minimize the potential for adversaries to the enrollment process. However, we may also envision enrollment occurring in open settings (e.g., over the Internet), and in such cases, there may be little control over the network path between the platform and the ACA. For our purposes, there are two general adversary types: off-path adversaries, who are not directly in the network path between the communicating parties, and inline or on-path adversaries, who are capable of "cutting the line of communication" if desired, and of performing arbitrary manipulations on the data stream. In addition to lurking on the path between the endpoints and manipulating the data flowing in either direction, inline adversaries may take on the role of an endpoint, e.g. a malicious platform, relying party, or ACA.

We may further sub-divide both on and off-path adversaries into active versus passive adversaries. Passive adversaries simply "listen", without interfering in any way, whereas active adversaries may interact with the traffic flow. Following are brief descriptions of the capabilities of off-path and inline adversaries.

Capabilities of an off-path adversary:

- Observe/record packets; note that while it is possible that an off-path adversary sees only a subset of the traffic, we assume that all traffic is visible for our worst-case analysis.
- Inject packets
- Replay packets
- Redirect/reflect packets/traffic

Capabilities of an inline adversary:

- Observe/record packets
- Inject packets
- Replay packets
- Redirect (or reflect) packets/traffic
- Delete packets
- Modify packets
- Delay packets

- Impersonate one of the communicating parties

Put succinctly, we assume that an inline adversary has full control over the communication channel between the communicating parties, and further, may attempt to impersonate either party in the communication. They may perform arbitrary manipulations on the data flow. Off-path adversaries are less capable, and lack a number of destructive capabilities, but may still cause significant problems.

In the following sections, we assume that no security measures are in place, and look at how the adversary might use these capabilities to create threats to the platform, the relying party, and the ACA.

9.2 Threats to the Platform and Platform Owner

In order to evaluate the threats to the platform and platform owner, we first enumerate the related assets, and then look at the various ways in which an adversary might interact with those assets. From the perspective of the platform owner, the following are assets that might be of interest to an attacker:

- Confidentiality and Anonymity
 - The platform owner may wish that the public EK remain confidential
 - The platform owner may wish that the AIK not be correlated with the EK, and not be disclosed without explicit approval of the platform owner
 - The platform owner may decide that EK/Platform Certificates contain information which must remain confidential
- Availability of ACA
 - The ACA must be available when the platform wishes to enroll an AIK; preventing AIK enrollment might interfere with other critical operations of the platform.
- Availability of Repository Services
 - ACA Repository Services must be available when the platform owner wishes to access them, e.g. in order to review the ACA's CP/CPS prior to making an enrollment decision. Further, if Repository Services are not available when the platform makes a request of the relying party, the relying party may refuse the request.
 - Access to ACA/ARA trust chain repository services (e.g., repository services relating to the trust chain that certifies the ACA and ARA certificates may be required prior to enrollment (so that the platform can perform path validation for RA/CA certificates), depending on the particulars of the implementation.
- Processing resources (TPM, CPU, storage)
 - The processing resources of the platform must be available for normal (and potentially critical) operations
- Ability to accurately determine the current time (for purposes of path validation, auditing, etc.)

Threats to the platform will be involve actions which adversely impact or compromise these assets. In the following subsections, we derive a list of related threats.

9.2.1 Information Disclosure

Due to the platform's requirement for confidentiality and anonymity, private information must be protected from disclosure. In cases where all Enrollment Domain Participants (EDPs) are under the control of one entity, existence of related threats will depend on whether intra-EDP communications are secure from outside view.

9.2.1.1 EK, Platform, Certificate, AIK

The EK certificate, platform certificate, and the AIK certificate may be considered PII by the platform owner, whether or not it is actually PII. Unprotected enrollment may result in advertent disclosure to on or off-path adversaries.

9.2.1.2 Frequency and timing of AIK certificate generation

The frequency with which a given platform obtains new AIK certificates and the timing of these may provide information which can be correlated with AIK usage.

9.2.1.3 ACA impersonation

If the ACA is successfully impersonated in an enrollment exchange, this will result in disclosure of information the platform owner may consider to be PII.

9.2.2 Denial of Service (DoS)

Due to the platform's requirement for ACA and Repository Services availability, denial of service conditions can adversely impact the platform. There are various forms of DoS, some of which can be addressed by the enrollment protocol, and some of which cannot.

9.2.2.1 ACA impersonation

If the ACA is successfully impersonated in an enrollment exchange and the platform obtains an invalid credential as a result, this may result in subsequent denial of service. ACA impersonation may be comprehensive, e.g. the attacker is the only party the platform communicates with, or it may be partial, e.g. the attacker modifies valid ACA traffic, or injects ACA traffic during a valid ACA-platform exchange. Such attacker-originated traffic, if taken to be genuine, may result in various outcomes which result in a denial of ACA service to the platform.

9.2.2.2 ACA or Repository Services Flooding

If the ACA or related repository services are overwhelmed with service requests, these may not be able to respond to a legitimate platform request. While this is properly an ACA/repository threat, since it impacts the platform, we mention it here.

9.2.2.3 ACA or Repository Services Misdirection

If the platform is unable to reach the ACA, e.g., due to spoofed DNS replies, dropped packets, or other on-path interference, this will result in a denial of ACA service to the platform.

9.3 Threats to the Relying Party

As in our evaluation of platform threats above, we similarly enumerate the assets of the relying party, and then look at the various ways in which an adversary might interact with those assets. It is important to note that the relying party is not a participant in the enrollment process (or at least, not in the currently defined use cases on which this specification is based). This means that there really is only one enrollment related "asset" from the perspective of the relying party, and that is the integrity of the enrollment process itself. The relying party depends on the factuality of its assumptions – that the certification and issuance policies of the ACA are effectively enforced, and cannot be subverted. If a platform can obtain a fraudulent AIK certificate due to a flawed enrollment process, all is lost for the relying party.

9.4 Threats to the Attestation CA and Repository Services

As in our evaluation of platform and relying party threats above, we similarly enumerate the assets of the Attestation CA and Repository Services, and then look at the various ways in which an adversary might interact with those assets. While general system security is a very important consideration for almost any CA, we do not attempt to address this in depth here. If an attacker is able to compromise the ACA, virtually all ACA assets are at risk, but from the perspective of an enrollment protocol, this is not within scope. This is not to say that appropriate system security measures should not be in place, but rather, that for our purposes, we assume this to be the case, and instead focus on assets directly relating to AIK enrollment and use. Following are assets that might be of interest to an attacker:

- Certification of AIKs
 - Attacker causes the ACA to certify a key which is not an AIK
 - Attacker causes the ACA to accept an invalid EK and/or platform certificate in the process of certifying an AIK
 - Attacker presents valid EK/platform certificates, but does not possess related EK
- Availability
 - Attacker causes loss or severe degradation of network connectivity
 - Attacker causes storage depletion
 - Attacker causes CPU/memory depletion
- Confidential Information
 - Platform-related information
 - Attacker causes disclosure of EK and/or AIK value
 - Attacker causes disclosure of EK/AIK binding
 - Attacker causes disclosure of Platform certificate content
 - Transaction information
 - Platforms
 - When did platform x request an AIK certificate?
 - Relying parties
 - When did RP x request status information on AIK certificate y?
- Timely Access to Repository Service
 - CRL or OCSP responder
- Access to reference manifest information (ACA may need reference manifest information in order to complete an enrollment)
 - Reference manifest availability
 - Transaction confidentiality
- Ability to determine the current time (for purposes of certificate timestamps, path validation, auditing, etc.)

9.4.1 Denial of Service (DoS)

Platforms and relying parties depend on ACA availability for various services, and denial of service conditions can adversely impact them, as well as the ACA itself. There are various forms of DoS, some of which can be addressed by the enrollment protocol, and some of which cannot.

9.4.1.1 Spoofed enrollment requests

AN ACA may be flooded with seemingly valid enrollment requests which cause the ACA to over-utilize various resources, including memory, cryptographic processing power, and storage.

9.4.1.2 Relying Party Impersonation

If the ACA directly implements repository services, a malicious entity may impersonate a relying party, and attempt to flood the ACA with various repository service requests.

9.5 Combined Threats

9.5.1 Information Disclosure

If the ACA queries a specific EK or Platform certificate status repository upon receiving a request, this leaks information about the request. The same is true if the ACA queries a reference manifest repository, and especially if such queries have no confidentiality protection.

9.5.2 Man in the Middle Attacks

A malicious party may exist in any of the following:

1. along the path between the platform and the ARA
2. on the path between the ARA and the ACA
3. on the path between platform the relying party
4. on the path between the relying party and the repository services.

Threats arising due to (3) and (4) are discussed above in sections 8.2 and 8.3. Threats arising due to (1) and (2) are discussed below.

9.5.2.1 Between Platform and ARA/ACA

A MITM between the platform and ARA/ACA poses threats to the platform, to the ACA, and to the enrollment process itself.

9.6 Trust Model

In addition to describing threats that may be encountered in the enrollment process, it is important to articulate the trust relationships and assumptions. That is the aim of this section

9.6.1 Trusting the Attestation CA

The attestation CA is pivotal in AIK enrollment and usage scenarios, and all enrollment domain participants must trust the ACA:

- The ACA is trusted by the enrollee to fully disclose its issuance policies and enrollment practices in the CP/CPS, and to always abide by these policies
- The ACA, if it makes privacy guarantees in its CP/CPS, is trusted by the enrollee to protect PII accordingly
- The ACA is trusted by the enrollee, through its repository services, to permit for timely revocation (as stated in its CP/CPS) and to update its certificate status information accordingly
- The ACA, through its repository services, is trusted by the relying party to permit for timely revocation, and to provide accurate and up to date certificate status information

There are a number of other, implicit trust assumptions which derive from the statements above, but we don't attempt to exhaustively enumerate them here. The ACA's CP/CPS may provide any number of assertions in which the enrollee and/or the relying party will trust. The most important point is that both the enrollee and relying party must implicitly trust the ACA to abide by its published policies and practices.

9.6.2 Trusting the Relying Party

In general, the relying party enjoys no special trust relationships. The platform owner may trust the relying party for various things not relating to the AIK enrollment, but with respect to AIKs themselves, the platform owner may assume the relying party is completely untrustworthy, and derive a new AIK for each and every transaction. Alternatively, it may trust the relying party implicitly – but this is irrelevant with respect to the enrollment protocol.

The ACA may implement access controls on its repository services which limit who can make queries, but such trust management decisions are outside the scope of enrollment.

9.6.3 Trusting the Platform Owner (Enrollee)

In general, the enrollee is trusted to protect and not share its enrollment credentials (e.g. the shared secret and/or private key used to authenticate enrollment requests). The ACA may also choose to relax to certain controls (e.g. the EK proof of possession in the enrollment protocol), but such trust decisions are outside the scope of this specification. In particular, we assume that the enrollee may attempt to “cheat” during enrollment, and we attempt to provide security controls to mitigate the resulting threats.

SECTION III: References and Appendices

10 References

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11 Appendix A – Specific Use Cases

11.1 Network Infrastructure Devices

As networking applications increase in complexity, so do the related security concerns. Some network equipment manufacturers are adding security features to infrastructure equipment which aim to address some of these concerns. There are currently IEEE standards, some ratified and some still under development, which articulate methods for strongly authenticating network devices, and securing inter-device communications[18][19][20]. These standards rely on public key cryptography for device authentication.

Additionally, some vendors are including TPM's in networking equipment. These may be used for all of the same applications as in personal computers, including storage security, strong device authentication, and platform integrity measurement and management. Related use cases are described below.

11.1.1 Secure/Trusted Boot

Network devices may implement various security measures meant to thwart tampering or device compromise, including secure/trusted boot. From a high-level, there are essentially two distinct classes of secure/trusted boot use cases: single vendor, turnkey solutions, and multi-vendor, interoperable scenarios. This leads to the following use case definitions:

- UC.NID.TB.1 – vendor provides standards-based hooks that allow customers and/or value-add service providers to provision and manage their own trusted boot applications
- UC.NID.TB.2 – vendor provides all elements of the solution.

In the following sections, we look at each of these use cases in more detail.

11.1.1.1 UC.NID.TB.1 – Vendor Provides Standards-Based Hooks

Walking through a typical usage scenario, let's assume a customer wants to issue local AIK certificates and implement trusted boot – what will be required? In general, vendors provide the firmware that runs on these devices, and do not support the loading of arbitrary images. So first, the vendor must publish reference manifests, so that relying parties have something to compare measurements against.

Second, the vendor has to ensure that the device ships with the elements necessary for AIK enrollment (i.e. the EK and platform certificates, or the means to retrieve them). Note that if these credentials are retrievable online, there may be associated privacy and security considerations to be taken into account. Alternatively, the device vendor may provide the means to enroll for these post-manufacturing (“late” enrollment). Finally, the vendor must provide AIK enrollment support in the product.

When the customer wants to provision an AIK certificate to a device, they will have to complete the following steps (assuming they have an ACA installed):

- Prepare to enroll for an AIK certificate; this implies support for the following:
 - Ability to take ownership and/or supply the owner key
 - AIK generation
- ACA trust anchor configuration (signing and encryption key certificates, plus trust anchor chain)
 - Some way to obtain the EK and Platform certificates – these may reside on the device, or be shipped with the device, e.g. on a CD. Alternatively, these may be provisioned by the customer.
- Submit the request to the ACA

- Ideally, this request will be submitted automatically, over a network connection, using the enrollment protocol defined in this specification.

The ACA will then have to do the following:

- Perform path validation of the EK certificate
 - This may require retrieving the EK CA certificate chain
 - This may require either retrieving one or more up-to-date CRLs, and/or contacting one or more OCSP responders
- Perform path validation of the Platform certificate
 - This may require retrieving the Platform CA certificate chain
 - This may require either retrieving one or more up-to-date CRLs, and/or contacting one or more OCSP responders
- Verify Proof of Possession (PoP) for the EK/AIK jointly
- Issue AIK certificate

Once the device is enrolled, the following is required:

- The ability to obtain reference measurements for the device. These will vary based on device revision, boot loader version, and firmware version(s), so every time the vendor provides a firmware update, new reference measurements will be required
- The device must take the measurements when initializing, and then make the measurements available somehow.
- The ACA must provide lifecycle management services for the AIK certificate (e.g. CRL updates, OCSP responder services)

This use case has an additional implicit requirement: someone has to integrate the elements of the solution. This might be the customer, a value-added reseller (VAR), an integrator, or some other third party service provider.

11.1.1.2 UC.NID.TB.2 – Vendor Provides Turn-Key Solution

As an added service to customers, a vendor may provide a turn-key trusted boot solution. There are at least two ways in which this might be provided using standard TCG elements. In the first, the vendor provisions all credentials as part of the manufacturing process. In the second, the vendor provides, as part of the overall solution, an ACA with which customers can create their own, individual domain. In either case, the device vendor is acting in a service provider role.

In the case where the vendor provisions all elements as part of the manufacturing process, there are no “moving parts” from the customer perspective – the presence of AIK credentials and related infrastructure is essentially invisible. Therefore, this variant seems to impose no interoperability requirements in terms of enrollment.

In the case where the vendor provides an ACA element as part of the solution package (e.g. ACA is an element of a vendor-provided network management system), the resulting requirements are dependent on whether or not either the device or the ACA is expected to interoperate with other elements which are not a direct part of the vendor-supplied solution. In the case where the solution is wholly self-contained, then the only apparent requirements are in terms of enrollment security, i.e. the vendor must provide security mechanisms aimed at ensuring the following:

- Enrollment is strongly authenticated
 - Only authorized devices are allowed to request certificates
 - Only an authorized ACA can tender enrollment requests

- If enrollment exposes confidential information of any sort, the enrollment protocol supports confidentiality, and/or the enrollment process occurs either offline or as part of pre-deployment staging, in a protected environment

11.1.2 Storage Security

TPM-based storage security, while certainly a valid use case for network devices, does not require an AIK, and involves no AIK-relevant interoperability requirements. Therefore, related usage scenarios are not discussed further here.

11.1.3 Strong Device Authentication

TPM's provide support for strong device authentication based on *Certified Keys* (CKs), RSA keys which are guaranteed to have been generated in and to have exclusively resided within a TPM. These keys differ from ordinary RSA keys in that CKs are bound to a specific TPM which is, presumably, physically bound to a specific device. Therefore, CKs have an advantage over ordinary RSA keys, in that the assurance that a related signature was created by a specific device is potentially much greater.

11.1.3.1 High-Level Use Case Overview

Use cases for device authentication are many and varied, but our focus here is explicitly on network infrastructure devices, which significantly narrows the field. In general, these scenarios involve either symmetric device authentication as part of a cryptographic key exchange (such as might be used in [19]), or asymmetric authentication, such as when a certified key is used to authenticate the device when terminating an administrative connection using a protocol such as SSL/TLS. For simplicity, this can be represented as a single use case:

- UC.NID.SDA.1 – device authentication as part of a cryptographic key exchange (e.g. in IKE, TLS/SSL, etc)

In the following section, we look at this use case in more detail.

11.1.3.2 UC.NID.SDA.1 - Device Authentication for Key Exchange

Inter-device authentication for network infrastructure devices is an emerging trend, one of which we will likely see more of in the near future[18][19][20]. In addition, many infrastructure device vendors (e.g. IPsec-based VPN gateway vendors) currently provide for some sort of secure, inter-device communications which might also benefit from use of Certified Keys. Similarly, devices may authenticate with a CK when terminating secure administrative connections.

While it is possible to provide single-vendor turnkey solutions which utilize pre-provisioned credentials, the more interesting cases involve dynamic provisioning and use of Certified Key certificates. In these cases, there are interesting nuances resulting from the dependence of the CK certificate upon the AIK certificate. To better illustrate this, let's look at how the CK is used:

- Device presents its CK certificate (and the signature it is meant to validate)
- The relying party validates the signature and trust anchor path
- The relying party (RP) validates the SKAE
 - obtains the AIK certificate and validates it
 - validates the signature over the TPM_CERTIFY_INFO structure in the SKAE
 - either validates that TPM_CERTIFY_INFO refers to public CK, or ensures that CA validated this prior to issuing CK certificate
 - grants access to requested resource

Prior to using the CK certificate, the device will have enrolled according to the description given above. This implies the following:

- device has access to its EK and platform certificates

- ACA has trust relationship with EK and platform certificate issuers, and can accomplish path validation for these certificates
- Device has obtained AIK certificate for the AIK with which it intends to sign the CK.
- CK certificate issuer (CA) understands SKAE, will include it in certificate
- CK CA either validates SKAE prior to issuing certificate, or clearly indicates that this is not done (e.g. in its Certificate Policy).

In order to use the CK certificate successfully, the following must be true with respect to the RP:

- RP trusts the ACA
- RP either possesses ACA trust anchor chain, or has the ability to obtain these (whether provided within the protocol the RP and device are performing authentication for, or by some other means). Note that it is not typical to allow Internet access for infrastructure devices, and in cases where this is not permitted, up-to-date certificate status information must be somehow made available to these devices.
- RP is able to validate the SKAE
 - Has access to up-to-date status info for AIK certificate, e.g. CRL or OCSP responder access, OR
 - Has assurance that the CK CA validated AIK certificate and SKAE as a precondition for issuing CK certificate
- RP trusts the CK certificate issuer, and is able to validate the CK certificate chain

Note the dependence of the CK certificate validation process on the AIK certificate – that is, if the AIK certificate is expired, the CK certificate may still be valid, yet the SKAE cannot be validated. This is a consequence of the fact that the CK CA does not always validate the SKAE (or AIK certificate) prior to issuing the CK certificate, so the lifetimes are disjoint. For this reason, CK implementers will be well advised to pay special attention to AIK certificate lifetimes, and the associated deployment problems.

11.1.4 Enrollment Scenarios for Network Infrastructure Devices

Based on the use cases described above, multiple enrollment scenarios are possible. For example, in a turnkey trusted boot solution (UC.NID.TB.2), all certificates may be provided during the device manufacture phase, including the AIK certificate. In such cases, the vendor is presumably in control of the enrollment environment, so there seem to be no specific confidentiality or integrity requirements on the enrollment protocol that result from this scenario.

On the other hand, other scenarios (e.g. UC.NID.TB.1, UC.NID.SDA.1) imply post-manufacturing enrollment scenarios, potentially involving multiple vendors and participants. In such cases, we cannot assume that requirements for confidentiality, integrity, etc. can be controlled by one party – these must be supplied by the enrollment protocol.

Protocol Design Requirement DR.410: The enrollment protocol used for network infrastructure devices must support confidentiality and integrity assurance mechanisms (e.g. such as those provided by TLS, IPsec, etc.)

11.2 Enterprise Platforms

TPM's are increasingly common in servers, desktop, and laptop computers, but the market is relatively young, and the population of applications utilizing AIK's today remains relatively sparse. Still, there may be enough of a sampling to give a general sense of some potentially interesting use cases, and this section aims to explore those areas where AIK's might be used in enterprise platform in order to better understand the requirements these uses impose on an enrollment protocol.

While enterprise platforms are in many ways similar to the network infrastructure devices described above, they differ in several important ways. For one, enterprise system users sometimes have administrative privileges, giving them the ability to modify the system “on the fly”. Another important difference is in the system software configuration. While network devices typically run firmware that is provided by a single vendor as a non-modifiable package, enterprise platforms within a given organization may vary widely in terms of hardware, operating system and version, and software package configuration.

This variability leads to some unique challenges when describing the associated use cases. In particular, while we can think of network infrastructure solutions in terms of hardware-vendor-supplied vs. 3rd party solutions, we must approach enterprise platforms differently. This is due to the fact that there are frequently different collections of entities involved in the fabrication, assembly, configuration, and deployment of these systems. This is discussed further below in the affected use cases.

11.2.1 Secure/Trusted Boot and Attestation

As with network devices, enterprise platforms may implement security measures meant to thwart or detect tampering or device compromise. The currently fielded solutions typically fall in one of two categories: those provided by the Operating System vendor or community, and those provided by 3rd party vendors.

None of the OS vendor/community solutions presently utilize AIK’s, and so they are not currently relevant for our purposes. But, this is not to say that they couldn’t be. For example, one way to implement secure boot with a TPM is to seal critical data (keys, passwords, etc.) to a TPM key, based on platform state data represented in PCR’s. As an alternative, one could envision a solution in which a sealing key would be managed by a separate system that requires successful attestation in order to release the key to the platform. This would have the added benefit of allowing the key to be bound to a more dynamic system, one for which PCR values may change due to system updates, etc. However, no such implementations are widely available today.

Trusted boot implementations, in contrast to secure boot implementations, do not inhibit malware from being executed during the boot process, nor do they stop platforms from booting if malware is present. Rather, the presence of malware is measured and represented in the TPM’s PCRs. Thus, a challenger can determine its presence if an AIK is used to “Quote” the relevant PCRs. Users of Trusted Network Connect (TNC) [23] protocols are one potential consumer of this type of functionality, and this represents the most likely enterprise platform use case for AIK’s today.

The following use cases are examined below:

- UC.EPM.TB.1 – closed domain solutions, single or multi-vendor.
- UC.EPM.TB.2 – single vendor provides all elements of cross-domain solution
- UC.EPM.TB.3 – multiple vendors provide elements of cross-domain solution

11.2.1.1 UC.EPM.TB.1 – Closed Domain, Single or Multi-Vendor

Walking through a typical usage scenario, let’s assume an enterprise wants to issue AIK certificates and implement for use in attestation. What will be required to get started? In general, enterprise systems may vary widely in various aspects of their configuration, so the first order of business is to define baseline system configurations – what will be measured – and to create reference manifests [24] against which platform measurements will be compared.

Next, the enterprise must ensure that each device possesses the elements necessary for AIK enrollment, i.e. EK and platform certificates. In some cases, EK certificates are included with enterprise platforms, but frequently they are not, and currently, there are no known instances of OEMs providing platform certificates. This implies that the enterprise may have to generate one or both of these credentials prior to proceeding. Finally, enrollment software and supporting elements must be installed.

When the enterprise wants to provision an AIK certificate to a device, they will have to complete the following steps (assuming they have an ACA installed):

- Prepare to enroll for an AIK certificate; this implies support for the following:
 - Ability to take ownership of the platform TPM and/or supply the owner key
 - AIK generation
- ACA trust anchor configuration (signing and encryption key certificates, plus trust anchor chain)
- Some way to obtain the EK and Platform certificates – these may reside on the platform, or be shipped with the platform, e.g. on a CD. Alternatively, these may be provisioned by the enterprise.
- Submit the request to the ACA
 - Ideally, this request will be submitted automatically, over a network connection, using the enrollment protocol defined in this specification.

The ACA will then have to do the following:

- Perform path validation of the EK certificate
 - This may require retrieving the EK CA certificate chain, but in a closed environment, one might expect this to be directly available to the ACA.
 - This may require either retrieving one or more up-to-date CRLs, and/or contacting one or more OCSP responders, although in a closed environment, one might reasonably expect that revocation information is directly available to the ACA.
- Perform path validation of the Platform certificate
 - This may require retrieving the Platform CA certificate chain
 - This may require either retrieving one or more up-to-date CRLs, and/or contacting one or more OCSP responders
- Verify Proof of Possession (PoP) for the EK/AIK jointly
- Issue AIK certificate

Once the device is enrolled, the following is necessary for attestation to occur:

- The ability to obtain and maintain accurate reference measurements for the device on an ongoing basis. In general, updated reference measurements will be required every time there is a change to any of the elements included in the baseline (BIOS, MBR, operating system, measured applications, configuration files, etc.), so it is critical to maintain tight administrative control over platform configuration. For example, if the user is allowed to control operating system updates, the system may quickly become desynchronized with the baseline measurements, and will subsequently “fail” attestation checks.
- The device sub-systems (CRTM, OS, etc.) must take the measurements when initializing
- The device may require the ability to take dynamic run-time measurements
- The ACA must provide lifecycle management services for the AIK certificate (e.g. CRL updates, OCSP responder services)

11.2.1.2 UC.EPM.TB.2 – Cross Domain, Single Vendor

Cross-domain attestation applications seem destined to be quite limited in scope, because of the inherent difficulties they entail. The best example of an enterprise platform cross-domain use

case is found in “guest” network access, in which a visitor (perhaps from another organizational group, or from outside the enterprise entirely) is granted limited access to the host enterprise network. Assuming we intended to use platform attestation in these cases, we can assume that the host network would wish to measure certain platform qualities prior to granting access to resources.

If we take the optimistic view that this will be (or perhaps already is) deployed, then we must assume that, in order to overcome the practical issues of scale, either the granularity of measurements is quite limited, or the range of allowable hardware/software configurations is quite limited, or both. In the former case (where configurations vary widely), one might imagine that what would be measured might include elements of the following:

- Each element of the measurement chain of trust (CRTM, OS, etc.)
- Operating System, version and patch level fall within a limited range
- Specific Anti-Virus (AV) software with a limited range of versions and patch levels is running
- Specific firewall configuration is in place on the system
- Certain applications are or are not running
- Certain network ports are or are not open

In the latter case outlined above (strictly controlled range of allowable hardware/software configuration), we can assume that some sort of platform configuration conformance measurement would be required as part of the registration process. Since this is a single-vendor solution, this process might result in “late issuance” of EK/platform certificates by the enterprise (the case where EK/platform certificates are issued by an external entity is, by definition, multi-vendor, and is covered in UC.EPM.TB.3).

Enrollment of such devices would be very similar to that of a closed domain; the primary differences would be in the requirement for the conformance measurement and late issuance of the EK/Platform certificates. Since this is a cross-domain enrollment scenario (for which the ACA would likely reside in a different domain than the platform), the enrollment might occur across a potentially hostile network (e.g., the Internet). Since a requirement to support enrollment across a hostile network has already been defined (DR.420), this use case yields no new requirements.

11.2.1.3 UC.EPM.TB.3 – Cross Domain, Multi-Vendor

The cross-domain multi-vendor use case is very similar to the cross-domain single-vendor use case, described above. The primary differences would be in who provides the EK and Platform Certificates, leading to requirements around external path validation for the various certificates. Since similar functionality has been addressed in other areas, no new requirements are defined here.

11.2.2 Storage Security

In common enterprise environments, the enterprise Information Technology group (IT) often prefers to remotely provision critical security parameters to a platform. A common way to do so is to encrypt the data with a key, which could be a non-migrateable TPM key, stored on the platform. For this to work as expected, IT needs a way to remotely determine that the key required in order to access the data actually resides on the platform. Using an AIK to certify the key provides IT with the necessary confidence to trust the key is actually on the expected target platform.

In addition to managing storage of keys, passwords, etc. on platforms, many vendors also sell self encrypting drive (SED) hardware and full disk encryption (FDE) software to provide large scale storage security solutions. Before a remote server releases sensitive data to a remote drive, it may require assurance that the SED / FDE is present and turned on. The AIK can provide this

by Quoting the appropriate PCRs. This use case is a subset of Trusted Boot and thus will not be replicated here.

11.2.3 Strong Device Authentication

TPM's provide support for strong device authentication based on *Certified Keys* (CKs), which are guaranteed to be generated in and to exclusively reside within a TPM. These keys differ from ordinary RSA keys in that CKs are bound to a specific TPM. Therefore, CKs have an advantage over ordinary RSA keys, in that the assurance that a related signature was created by a specific device is potentially much greater.

Use cases for device authentication are many and varied, and frequently involve use of an asymmetric cryptographic key pair for authentication. AIK's become relevant when a certified key is used for this purpose, e.g. when using a protocol such as SSL/TLS. For simplicity, this can be represented as a single use case:

- UC.EPM.SDA.1 – device authentication as part of a cryptographic key exchange (e.g. in IKE, TLS/SSL, etc)

In the following section, we look at this use case in more detail.

11.2.3.1 Device Authentication for Key Exchange (UC.EPM.SDA.1)

Like the network device use case, clear benefits in terms of improved assurance derive from use of a hardware protected key, but in the case of an enterprise device, the value may be even higher. Given the number of system compromises regularly reported for such devices, one need not ponder long to recognize that while malware inhabiting a compromised system can still *use* a TPM-resident key, it cannot export it. This serves to limit the damage.

And while it is possible to provide single-vendor turnkey solutions which utilize pre-provisioned credentials, the more interesting cases involve dynamic provisioning and use of Certified Key certificates. In these cases, there are interesting nuances resulting from the dependence of the CK certificate upon the AIK certificate. To better illustrate this, let's look at how the CK is used:

- Platform presents its CK certificate (and the signature it is meant to validate)
- The relying party validates the signature and trust anchor path
- The relying party (RP) validates the SKAE
 - obtains the AIK certificate and validates it
 - validates the signature over the TPM_CERTIFY_INFO structure in the SKAE
 - either validates that TPM_CERTIFY_INFO refers to public CK, or ensures that CA validated this prior to issuing CK certificate
 - grants access to requested resource

Prior to using the CK certificate, the platform will have enrolled according to the description given above. This implies the following:

- platform has access to its EK and platform certificates
- ACA has trust relationship with EK and platform certificate issuers, and can accomplish path validation for these certificates
- Platform has obtained AIK certificate for the AIK with which it intends to sign the CK.
- CK certificate issuer (CA) understands SKAE, will include it in certificate

- CK CA either validates SKAE prior to issuing certificate, or clearly indicates that this is not done (e.g. in its Certificate Policy).

In order to use the certificate successfully, the following must be true with respect to the RP:

- RP trusts the ACA
- RP either possesses ACA trust anchor chain, or has the ability to obtain these (whether provided within the protocol the RP and platform are performing authentication for, or by some other means).
- RP is able to validate the SKAE
 - Has access to up-to-date status info for AIK certificate, e.g. CRL or OCSP responder access, OR
 - Has assurance that the CK CA validated AIK certificate and SKAE as a precondition for issuing CK certificate
- RP trusts the CK certificate issuer, and is able to validate the CK certificate chain

Note the dependence of the CK certificate validation process on the AIK certificate – that is, if the AIK certificate is expired, the CK certificate may still be valid, yet the SKAE cannot be validated. This is a consequence of the fact that the CK CA does not always validate the SKAE (or AIK certificate) prior to issuing the CK certificate, so the lifetimes are disjoint. For this reason, CK implementers will be well advised to pay special attention to AIK certificate lifetimes, and the associated deployment problems.

11.2.4 Enrollment Scenarios for Enterprise Platform Management

Based on the use cases described above, a number of variations on AIK enrollment are possible in the enterprise platform setting. In general, EK and platform certificates are not provided by existing vendors, so in virtually all cases, some form of “late issuance” is required for these. In closed environments, it is conceivable that the same CA infrastructure that issues AIK certificates (the ACA) is also responsible for issuance of EK and platform certificates, but other approaches are certainly possible.

Clearly, the confidence the ACA accords to EK/platform certificates issued by entities/processes other than the ACA must depend on the integrity of the late issuance process, and this is but one of the many complications that must be addressed to successfully and effectively utilize AIK certificates in a multi-vendor environment.