Security Automation and Continuous Monitoring (SACM) Architecture
draft-ietf-sacm-arch-03

Abstract

This memo defines a Security Automation and Continuous Monitoring
(SACM) architecture. This work is built upon [RFC8600], and is
predicated upon information gleaned from SACM Use Cases and
Requirements ([RFC7632] and [RFC8248] respectively), and terminology
as found in [I-D.ietf-sacm-terminology].

WORKING GROUP: The source for this draft is maintained in GitHub.
Suggested changes should be submitted as pull requests at
https://github.com/sacmwg/ietf-mandm-sacm-arch/. Instructions are on
that page as well.

Status of This Memo

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1. Introduction

The purpose of this draft is to define an architectural approach for a SACM Domain, based on the spirit of use cases found in [RFC7632] and requirements found in [RFC8248]. This approach gains the most advantage by supporting a variety of collection systems, and intends to enable a cooperative ecosystem of tools from disparate sources with minimal operator configuration.

1.1. Requirements notation

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119, BCP 14 [RFC2119].

2. Terms and Definitions

This draft defers to [I-D.ietf-sacm-terminology] for terms and definitions.

3. Architectural Overview

The generic approach proposed herein recognizes the need to obtain information from existing and future state collection systems, and makes every attempt to respect [RFC7632] and [RFC8248]. At the foundation of any architecture are entities, or components, that need to communicate. They communicate by sharing information, where, in a given flow, one or more components are consumers of information and one or more components are providers of information.
As shown in Figure 1, the SACM architecture consists of some basic SACM Components communicating using a component integration service. The component integration service is expected to maximally align with the requirements described in [RFC8248], which means that the component integration service will support brokered (i.e. point-to-point) and proxied data exchange.

The enterprise boundary is not intended to imply a physical boundary. Rather, the enterprise boundary is intended to be inclusive of various cloud environments and vendor-provided services in addition to any physical systems the enterprise operates.

3.1. Architectural Components

This document suggests a variety of players in a cooperative ecosystem - we call these players SACM Components. SACM Components may be composed of other SACM Components, and each SACM Component plays one, or more, of several roles relevant to the ecosystem. Generally each role is either a consumer of information or a provider of information. The Figure 1 diagram illustrates a number of SACM Components.
components which are architecturally significant and therefore warrant discussion and clarification.

3.1.1. Orchestrator

An Orchestration component exists to aid in the automation of configuration, coordination, and management for the ecosystem of SACM components. The Orchestrator performs control-plane operations, administration of an implementing organization’s components (including endpoints, posture collection services, and downstream activities), scheduling of automated tasks, and any ad-hoc activities such as the initiation of collection or evaluation activities. The Orchestrator is the key administrative interface into the SACM architecture.

3.1.2. Repositories/CMDBs

The Figure 1 diagram only includes a single reference to "Repositories/CMDBs", but in practice, a number of separate data repositories may exist, including posture attribute repositories, policy repositories, local vulnerability definition data repositories, and state assessment results repositories. These data repositories may exist separately or together in a single representation, and the design of these repositories may be as distinct as their intended purpose, such as the use of relational database management systems or graph/map implementations focused on the relationships between data elements. Each implementation of a SACM repository should focus on the relationships between data elements and implement the SACM information and data model(s).

3.1.3. Component Integration Service

If each SACM component represents a set of services, capabilities, and/or functions, the Component Integration Service represents the "fabric" by which all those services, capabilities and functions are woven together. The Component Integration Service acts as a message broker, combining a canonical data model, a common command set, and a messaging infrastructure to allow other SACM components to communicate using a shared set of interfaces. The Component Integration Service’s brokering capabilities enable the exchange of information, the orchestration of capabilities, message routing and reliable delivery. The Component Integration Service minimizes the dependencies from one system to another through the loose coupling of applications through messaging.

The Component Integration Service should provide mechanisms for synchronous "request/response"-style messaging, asynchronous "send and forget" messaging, or publish/subscribe. It is the
responsibility of the Component Integration Service to coordinate and manage the sending and receiving of messages. The Component Integration Service should allow components the ability to directly connect and produce or consume messages, or connect via message translators which can act as a proxy, transforming messages from a component format to one implementing a SACM data model.

A number of pieces come together to form the Component Integration Service:

1. Common communication infrastructure: The physical communications infrastructure, providing a cross-platform, cross-language universal adapter between SACM components. This infrastructure commonly includes message routing capabilities to facilitate the correct routing of messages from SACM component to SACM component, as well as using Publish/Subscribe functionality to facilitate sending messages to all receivers.

2. Adapters: The use of a standard, canonical data model will likely require SACM components to translate component-specific information into the canonical format used by the message broker.

3. Common command/interaction structure: Just as PC architectures have a common set of commands to represent the different operations possible on a physical bus, there must be common interactions that all SACM components can understand.

3.2. Sub-Architectures

The Figure 1 shows two components representing the architectural workflows involved in a cooperative ecosystem of SACM components: Collection and Evaluation. The following section, Architectural Workflows (TBD - ADD LINK) further expands on these components/workflows.

3.3. Downstream Uses

As depicted by Figure 1, a number of downstream uses exist in the cooperative ecosystem. Each notional SACM component represents distinct sub-architectures which will exchange information via the component integration services, using interactions described in this draft.

3.3.1. Reporting

The Reporting component represents the capabilities of the SACM architecture dealing with the query and retrieval of collected
posture attribute information, evaluation results, etc. in various display formats that are useful to a wide range of stakeholders.

3.3.2. Analytics

The Analytics component represents the capabilities of the SACM architecture dealing with the discovery, interpretation, and communication of any meaningful patterns of data in order to inform effective decision making within the organization.

4. Sub-Architectural Components

This section describes the workflows derived from the interactions with the two sub-architectures depicted in the Figure 1: Collection and Evaluation.

4.1. Collection Sub-Architecture

The Collection sub-architecture, in a SACM context, is the mechanism by which posture attributes are collected from applicable endpoints and persisted to a repository, such as a configuration management database (CMDB). Orchestration components will choreograph endpoint data collection via interactions using the Component Integration Service as a message broker. Instructions to perform endpoint data collection are directed to a Posture Collection Service capable of performing collection activities utilizing any number of methods, such as SNMP, NETCONF/RESTCONF, SSH, WinRM, or host-based.
4.1.1. Posture Collection Service

The Posture Collection Service (PCS) is the SACM component responsible for the collection of posture attributes from an endpoint or set of endpoints. A single PCS may be responsible for management of posture attribute collection from many endpoints. The PCS will interact with the Component Integration Service to receive collection instructions and to provide collected posture data for persistence to the Posture Attribute Repository. Collection instructions may be supplied in a variety of forms, including subscription to a publish/subscribe topic to which the Component Integration Service has
published instructions, via request/response-style synchronous messaging, or via asynchronous "send-and-forget" messaging. Collected posture information may then be supplied to the Component Integration Service via similar channels. The various interaction types are discussed later in this draft (TBD).

4.1.2. Endpoint

Building upon [I-D.ietf-sacm-terminology], the SACM Collection Sub-Architecture augments the definition of an Endpoint as a component within an organization’s management domain from which a Posture Collection Service will collect relevant posture attributes.

4.1.3. Posture Attribute Repository

The Posture Attribute Repository is a SACM component responsible for the persistent storage of posture attributes collected via interactions between the Posture Collection Service and Endpoints.

4.2. Evaluation Sub-Architecture

The Evaluation Sub-Architecture, in the SACM context, is the mechanism by which policy, expressed in the form of expected state, is compared with collected posture attributes to yield an evaluation result, that result being contextually dependent on the policy being evaluated.
4.2.1. Posture Evaluation Service

The Posture Evaluation Service represents the SACM component responsible for coordinating the policy to be evaluated and the collected posture attributes relevant to that policy, as well as the comparison engine responsible for correctly determining compliance with the expected state.

4.2.2. Policy Repository

The Policy Repository represents a persistent storage mechanism for the policy to be assessed against collected posture attributes to determine if an endpoint meets the defined expected state. Examples
of information contained in a Policy Repository would be
Vulnerability Definition Data or configuration recommendations as
part of a CIS Benchmark or DISA STIG.

4.2.3. Evaluation Results Repository

The Evaluation Results Repository persists the information
representing the results of a particular posture assessment,
indicating those posture attributes collected from various endpoints
which either meet or do not meet the expected state defined by the
assessed policy. Consideration should be made for the context of
individual results. For example, meeting the expected state for a
configuration attribute indicates a correct configuration of the
endpoint, whereas meeting an expected state for a vulnerable software
version indicates an incorrect and therefore vulnerable
configuration.

5. Interactions

SACM Components are intended to interact with other SACM Components.
These interactions can be thought of, at the level of this
architectural approach, as the combination of interfaces with their
supported operations. Each interaction will convey a payload of
information. The payload information is expected to contain sub-
domain-specific characteristics and instructions.

- *Publish/Subscribe*: A component publishes information to a
  messaging system and a set of other components, subscribed to that
  information type, receive the published information.

- *Request/Response*: A request/response interaction can take a
  number of forms, but will always be synchronous operations
  involving the requesting component waiting/blocking until a
  response is received from the requested component or a timeout
  occurs.

  * *Information Request*: An information request is simply one
    component requesting information from another component, such
    as an Orchestrator requesting collection capabilities from a
    Posture Collection Service.

  * *Query*: A query interaction can take one of two forms,
    "selection" or "storage".

    + __Selection__: A component requests data from a repository.
    + __Storage__: A component provides data to be persisted in a
      repository.
*Directive*: Commonly referred to as "Send-and-Forget", a directive is an asynchronous interaction whereby a component requests information from another component but does not wait/block for a response. The receiving component may reply later via callbacks or further interactions, but it is not mandatory.

Each interaction will convey a payload of information. The payload information is expected to contain sub-domain-specific characteristics and instructions.

6. Security Domain Workflows

This section describes three primary information security domains from which workflows may be derived: IT Asset Management, Vulnerability Management, and Configuration Management.

6.1. IT Asset Management

Information Technology asset management is easier said than done. The [CISCONTROLS] have two controls dealing with IT asset management. Control 1, Inventory and Control of Hardware Assets, states, "Actively manage (inventory, track, and correct) all hardware devices on the network so that only authorized devices are given access, and unauthorized and unmanaged devices are found and prevented from gaining access." Control 2, Inventory and Control of Software Assets, states, "Actively manage (inventory, track, and correct) all software on the network so that only authorized software is installed and can execute, and that unauthorized and unmanaged software is found and prevented from installation or execution."

In spirit, this covers all of the processing entities on your network (as opposed to things like network cables, dongles, adapters, etc.), whether physical or virtual.

An IT asset management capability needs to be able to:

- Identify and catalog new assets by executing Target Endpoint Discovery Tasks
- Provide information about its managed assets, including uniquely identifying information (for that enterprise)
- Handle software and/or hardware (including virtual assets)
- Represent cloud hybrid environments
6.2. Vulnerability Management

Vulnerability management is a relatively established process. To paraphrase the [CISCONTROLS], continuous vulnerability management is the act of continuously acquiring, assessing, and taking subsequent action on new information in order to identify and remediate vulnerabilities, therefore minimizing the window of opportunity for attackers.

A vulnerability assessment (i.e. vulnerability detection) is performed in two steps:

- Endpoint information collected by the endpoint management capabilities is examined by the vulnerability management capabilities through Evaluation Tasks.

- If the data possessed by the endpoint management capabilities is insufficient, a Collection Task is triggered and the necessary data is collected from the target endpoint.

Vulnerability detection relies on the examination of different endpoint information depending on the nature of a specific vulnerability. Common endpoint information used to detect a vulnerability includes:

- A specific software version is installed on the endpoint
- File system attributes
- Specific state attributes

In some cases, the endpoint information needed to determine an endpoint’s vulnerability status will have been previously collected by the endpoint management capabilities and available in a Repository. However, in other cases, the necessary endpoint information will not be readily available in a Repository and a Collection Task will be triggered to perform collection from the target endpoint. Of course, some implementations of endpoint management capabilities may prefer to enable operators to perform this collection even when sufficient information can be provided by the endpoint management capabilities (e.g. there may be freshness requirements for information).

6.3. Configuration Management

Configuration management involves configuration assessment, which requires state assessment. The [CISCONTROLS] specify two high-level controls concerning configuration management (Control 5 for non-
network devices and Control 11 for network devices). As an aside, these controls are listed separately because many enterprises have different organizations for managing network infrastructure and workload endpoints. Merging the two controls results in the following paraphrasing: Establish, implement, and actively manage (track, report on, correct) the security configuration of systems using a rigorous configuration management and change control process in order to prevent attackers from exploiting vulnerable services and settings.

Typically, an enterprise will use configuration guidance from a reputable source, and from time to time they may tailor the guidance from that source prior to adopting it as part of their enterprise standard. The enterprise standard is then provided to the appropriate configuration assessment tools and they assess endpoints and/or appropriate endpoint information.

A preferred flow follows:

- Reputable source publishes new or updated configuration guidance
- Enterprise configuration assessment capability retrieves configuration guidance from reputable source
- Optional: Configuration guidance is tailored for enterprise-specific needs
- Configuration assessment tool queries asset inventory repository to retrieve a list of affected endpoints
- Configuration assessment tool queries configuration state repository to evaluate compliance
- If information is stale or unavailable, configuration assessment tool triggers an ad hoc assessment

The SACM architecture needs to support varying deployment models to accommodate the current state of the industry, but should strongly encourage event-driven approaches to monitoring configuration.

7. Configuration Management Components and Capabilities

This section provides more detail about the components and capabilities required when considering the aforementioned configuration management workflow.
7.1. Components

The following is a minimal list of SACM Components required to implement the aforementioned configuration assessment workflow.

- Configuration Policy Feed: An external source of authoritative configuration recommendations.
- Configuration Policy Repository: An internal repository of enterprise standard configurations.
- Configuration Assessment Orchestrator: A component responsible for orchestrating assessments.
- Posture Attribute Collection Subsystem: A component responsible for collection of posture attributes from systems.
- Posture Attribute Repository: A component used for storing system posture attribute values.
- Configuration Assessment Evaluator: A component responsible for evaluating system posture attribute values against expected posture attribute values.
- Configuration Assessment Results Repository: A component used for storing evaluation results.

7.2. Capabilities

Per [RFC8248], solutions MUST support capability negotiation. Components implementing specific interfaces and operations (i.e. interactions) will need a method of describing their capabilities to other components participating in the ecosystem; for example, "As a component in the ecosystem, I can assess the configuration of Windows, MacOS, and AWS using OVAL".

8. Configuration Assessment Workflow

This section describes the components and interactions in a basic configuration assessment workflow. For simplicity, error conditions are recognized as being necessary and are not depicted. When one component messages another component, the message is expected to be handled appropriately unless there is an error condition, or other notification, messaged in return.
Figure 4: Configuration Assessment Component Interactions

Figure 4 depicts configuration assessment components and their interactions, which are further described below.


2. The Orchestrator obtains collection information from the Policy Repository: TODO - add specific interaction options here.

3. The Orchestrator initiates collection to be performed by the Collection Sub-Architecture: TODO - add specific interaction options here.


5. The Orchestrator initiates the Evaluator (optionally with evaluation information gathered from the Policy Repository): TODO - add specific interaction options here

   1. The Evaluator obtains evaluation information from the Policy Repository (optionally): TODO - add specific interaction options here
2. The Evaluator obtains relevant posture attributes from the Posture Attribute Repository: TODO – add specific interaction options here

6. Evaluation results are stored in the Evaluation Results Repository: TODO – add specific interaction options here

In the above flow, the payload information is expected to convey the context required by the receiving component for the action being taken under different circumstances. For example, the Tell message sent from an Orchestrator to a Collection sub-architecture might be telling that Collector to watch a specific posture attribute and report only specific detected changes to the Posture Attribute Repository, or it might be telling the Collector to gather that posture attribute immediately. Such details are expected to be handled as part of that payload, not as part of the architecture described herein.

9. Privacy Considerations

TODO

10. Security Considerations

TODO

11. IANA Considerations

TODO: Revamp this section after the configuration assessment workflow is fleshed out.

IANA tables can probably be used to make life a little easier. We would like a place to enumerate:

- Capability/operation semantics
- SACM Component implementation identifiers
- SACM Component versions
- Associations of SACM Components (and versions) to specific Capabilities
- Collection sub-architecture Identification
12. References

12.1. Normative References


12.2. Informative References


[I-D.ietf-sacm-terminology]

[NIST800126]

[NISTIR7694]

[RFC5023]

[RFC7632]

[RFC8248]
Appendix A. Mapping to RFC8248

TODO: Consider removing or placing in a separate solution draft.

This section provides a mapping of XMPP and XMPP Extensions to the relevant requirements from [RFC8248]. In the table below, the ID and Name columns provide the ID and Name of the requirement directly out of [RFC8248]. The Supported By column may contain one of several values:

- N/A: The requirement is not applicable to this architectural exploration
- Architecture: This architecture (possibly assuming some components) should meet the requirement
- XMPP: The set of XMPP Core specifications and the collection of applicable extensions, deployment, and operational considerations.
- XMPP-Core: The requirement is satisfied by a core XMPP feature
- XEP-nnnn: The requirement is satisfied by a numbered XMPP extension (see [XMPPEXT])
- Operational: The requirement is an operational concern or can be addressed by an operational deployment
- Implementation: The requirement is an implementation concern

If there is no entry in the Supported By column, then there is a gap that must be filled.

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Appendix B. Example Components

TODO: Consider removing.

B.1. Policy Services

Consider a policy server conforming to [RFC8322]. [RFC8322] describes a RESTful way based on the ATOM Publishing Protocol ([RFC5023]) to find specific data collections. While this represents a specific binding (i.e. RESTful API based on [RFC5023]), there is a more abstract way to look at ROLIE.

ROLIE provides notional workspaces and collections, and provides the concept of information categories and links. Strictly speaking, these are logical concepts independent of the RESTful binding ROLIE specifies. In other words, ROLIE binds a logical interface (i.e. GET workspace, GET collection, SET entry, and so on) to a specific mechanism (namely an ATOM Publication Protocol extension).

It is not inconceivable to believe there could be a different interface mechanism, or a connector, providing these same operations using XMPP-Grid as the transfer mechanism.

Even if a [RFC8322] server were external to an organization, there would be a need for a policy source inside the organization as well,
and it may be preferred for such a policy source to be connected directly to the ecosystem’s communication infrastructure.

B.2. Software Inventory

The SACM working group has accepted work on the Endpoint Posture Collection Profile [I-D.ietf-sacm-ecp], which describes a collection architecture and may be viewed as a collector coupled with a collection-specific repository.

Our assertion is that the Evaluator, Repository, Orchestrator, and Posture Manager all have the potential to represent SACM Components with specific capability interfaces that can be logically specified, then bound to one or more specific transfer mechanisms (i.e. RESTful API, [RFC8322], [RFC8600], and so on).
B.3. Datastream Collection

[NIST800126], also known as SCAP 1.3, provides the technical specifications for a "datastream collection". The specification describes the "datastream collection" as being "composed of SCAP data streams and SCAP source components". A "datastream" provides an encapsulation of the SCAP source components required to, for example, perform configuration assessment on a given endpoint. These source components include XCCDF checklists, OVAL Definitions, and CPE Dictionary information. A single "datastream collection" may encapsulate multiple "datastreams", and reference any number of SCAP components. Datastream collections were intended to provide an envelope enabling transfer of SCAP data more easily.

The [NIST800126] specification also defines the "SCAP result data stream" as being conformant to the Asset Reporting Format specification, defined in [NISTIR7694]. The Asset Reporting Format provides an encapsulation of the SCAP source components, Asset Information, and SCAP result components, such as system characteristics and state evaluation results.

What [NIST800126]did not do is specify the interface for finding or acquiring source datastream information, nor an interface for publishing result information. Discovering the actual resources for this information could be done via ROLIE, as described in the Policy Services section above, but other repositories of SCAP data exist as well.

B.4. Network Configuration Collection

[draft-birkholz-sacm-yang-content] illustrates a SACM Component incorporating a YANG Push client function and an XMPP-grid publisher function. [draft-birkholz-sacm-yang-content] further states "the output of the YANG Push client function is encapsulated in a SACM Content Element envelope, which is again encapsulated in a SACM statement envelope" which are published, essentially, via an XMPP-Grid Connector for SACM Components also part of the XMPP-Grid.

This is a specific example of an existing collection mechanism being adapted to the XMPP-Grid message transfer system.

Appendix C. Exploring An XMPP-based Solution

TODO: Consider removing or placing in a separate draft.

Ongoing work has been taking place around and during IETF hackathons. The list of hackathon efforts follows:
- **HACK99**: A partial implementation of a vulnerability assessment scenario involving an [I-D.ietf-sacm-ecp] implementation, a [RFC8322] implementation, and a proprietary evaluator to pull the pieces together.

- **HACK100**: Work to combine the vulnerability assessment scenario from [HACK99] with an XMPP-based YANG push model.

- **HACK101**: A fully automated configuration assessment implementation using XMPP (specifically Publish/Subscribe capabilities) as a communication mechanism.

- **HACK102**: An exploration of how we might model assessment, collection, and evaluation abstractly, and then rely on YANG expressions for the attributes of traditional endpoints.

- **HACK103**: No SACM participation at the Bangkok hackathon.

- **HACK104**: Basic XMPP-to-Concise MAP - Created an XMPP adapter that can accept basic posture attributes and translate them to Concise MAP. This hackathon only proved the concept that system characteristics information can be transported via XMPP and translated to a (very basic) concise MAP implementation.

- **HACK105**: Advanced XMPP-to-Concise MAP: Full orchestration of collection capabilities using XMPP. Collector implementations extend the core XMPP structure to allow OVAL collection instructions (OVAL objects) to inform posture attribute collection. Collected system characteristics can be provided to the Concise MAP XMPP adapter using all 3 available XMPP capabilities: Publish/Subscribe, Information Query (iq - request/response) stanzas, or direct Message stanzas. CDDL was created to map collected posture attributes to Concise MAP structure. The XMPP adapter translates the incoming system characteristics and stores the information in the MAP.

Figure 6 depicts a slightly more detailed view of the architecture (within the enterprise boundary) - one that fosters the development of a pluggable ecosystem of cooperative tools. Existing collection mechanisms can be brought into this architecture by specifying the interface of the collector and creating the XMPP-Grid Connector binding for that interface.

Additionally, while not directly depicted in Figure 6, this architecture does allow point-to-point interfaces. In fact, [RFC8600] provides brokering capabilities to facilitate such point-to-point data transfers. Additionally, each of the SACM Components...
depicted in Figure 6 may be a provider, a consumer, or both, depending on the workflow in context.

```
+--------------+           +--------------+
| Orchestrator |           | Repositories |
+--------------+           +--------------+

+-------v-------+           +-------v-------+
| XMPP-Grid+ |           | Downstream Uses |
+--------------+           +--------------+

Figure 6: XMPP-based Architecture
```

[RFC8600] details a number of XMPP extensions (XEPs) that MUST be utilized to meet the needs of [RFC7632] and [RFC8248]:

- Service Discovery (XEP-0030): Service Discovery allows XMPP entities to discover information about other XMPP entities. Two kinds of information can be discovered: the identity and capabilities of an entity, such as supported features, and items associated with an entity.

- Publish-Subscribe (XEP-0060): The PubSub extension enables entities to create nodes (topics) at a PubSub service and publish information at those nodes. Once published, an event notification is broadcast to all entities that have subscribed to that node.

At this point, [RFC8600] specifies fewer features than SACM requires, and there are other XMPP extensions (XEPs) we need to consider to meet the needs of [RFC7632] and [RFC8248]. In Figure 6 we therefore use "XMPP-Grid+" to indicate something more than [RFC8600] alone, even though we are not yet fully confident in the exact set of XMPP-related extensions we will require. The authors propose work to extend (or modify) [RFC8600] to include additional XEPs - possibly the following:
- **Entity Capabilities (XEP-0115):** This extension defines the methods for broadcasting and dynamically discovering an entities’ capabilities. This information is transported via standard XMPP presence. Example capabilities that could be discovered could include support for posture attribute collection, support for specific types of posture attribute collection such as EPCP, SWIMA, OVAL, or YANG. Other capabilities are still to be determined.

- **Ad Hoc Commands (XEP-0050):** This extension allows an XMPP entity to advertise and execute application-specific commands. Typically the commands contain data forms (XEP-0004) in order to structure the information exchange. This extension may be usable for simple orchestration (i.e. "do assessment").

- **HTTP File Upload (XEP-0363):** The HTTP File Upload extension allows for large data sets to be published to a specific path on an HTTP server, and receive a URL from which that file can later be downloaded again. XMPP messages and IQs are meant to be compact, and large data sets, such as collected posture attributes, may exceed a message size threshold. Usage of this XEP allows those larger data sets to be persisted, thus necessitating only the download URL to be passed via XMPP messages.

- **Personal Eventing Protocol (XEP-0163):** The Personal Eventing Protocol can be thought of as a virtual PubSub service, allowing an XMPP account to publish events only to their roster instead of a generic PubSub topic. This XEP may be useful in the cases when collection requests or queries are only intended for a subset of endpoints and not an entire subscriber set.

- **File Repository and Sharing (XEP-0214):** This extension defines a method for XMPP entities to designate a set of file available for retrieval by other users of their choosing, and is based on PubSub Collections.

- **Easy User Onboarding (XEP-401):** The goal of this extension is simplified client registration, and may be useful when adding new endpoints or SACM components to the ecosystem.

- **Bidirectional-streams Over Synchronous HTTP (BOSH) (XEP-0124):** BOSH emulates the semantics of a long-lived, bidirectional TCP connection between two entities (aka "long polling"). Consider a SACM component that is updated dynamically, i.e. an internal vulnerability definition repository ingesting data from a Feed/Repository of External Data, and a second SACM component such as an Orchestrator. Using BOSH, the Orchestrator can effectively
continuously poll the vulnerability definition repository for changes/updates.

- **PubSub Collection Nodes (XEP-0248):** Effectively an extension to XEP-0060 (Publish-Subscribe), PubSub Collections aim to simplify an entities’ subscription to multiple related topics, and establishes a "node graph" relating parent nodes to its descendents. An example "node graph" could be rooted in a "vulnerability definitions" topic, and contain descendent topics for OS family-level vulnerability definitions (i.e. Windows), and further for OS family version-level definitions (i.e. Windows 10 or Windows Server 2016).

- **PubSub Since (XEP-0312):** This extension enables a subscriber to automatically receive PubSub and Personal Eventing Protocol (PEP) notifications since its last logout time. This extension may be useful in intermittent connection scenarios, or when entities disconnect and reconnect to the ecosystem.

- **PubSub Chaining (XEP-0253):** This extension describes the federation of publishing nodes, enabling a publish node of one server to be a subscriber to a publishing node of another server.

### C.1. Example Architecture using XMPP-Grid and Endpoint Posture Collection Protocol

Figure 7 depicts a further detailed view of the architecture including the Endpoint Posture Collection Protocol as the collection subsystem, illustrating the idea of a pluggable ecosystem of cooperative tools.
Figure 7: XMPP-based Architecture including EPCP
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