User Guide

AWS Nitro Enclaves

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AWS Nitro Enclaves: User Guide

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Table of Contents

What is Nitro Enclaves? ... 1
Learn more ... 2
Requirements ... 2
Considerations ... 11
Pricing ... 12
Related services ... 12
Nitro Enclaves concepts ... 14
Enclave ... 14
Enclave ID ... 14
Parent instance ... 15
Enclave image file ... 15
AWS Nitro Enclaves CLI ... 15
AWS Nitro Enclaves SDK ... 15
Cryptographic attestation ... 15
Attestation document ... 15
Platform configuration registers ... 16
KMS proxy ... 16
Vsock socket ... 16
Enclave workflow overview ... 17
Involved parties ... 17
Data and environment preparation ... 18
Attestation and data decryption ... 18
Nitro Enclaves application development ... 19
Nitro Enclaves Developer AMI ... 20
Nitro Enclaves SDK ... 20
Application development on Linux ... 20
Application development on Windows ... 23
Building an enclave image file ... 36
Creating an enclave ... 38
Launch the parent instance ... 39
Create the enclave ... 40
Getting started with Nitro Enclaves ... 42
Getting started: Hello Enclaves ... 42
Step 1: Prepare the enclave-enabled parent instance ... 43

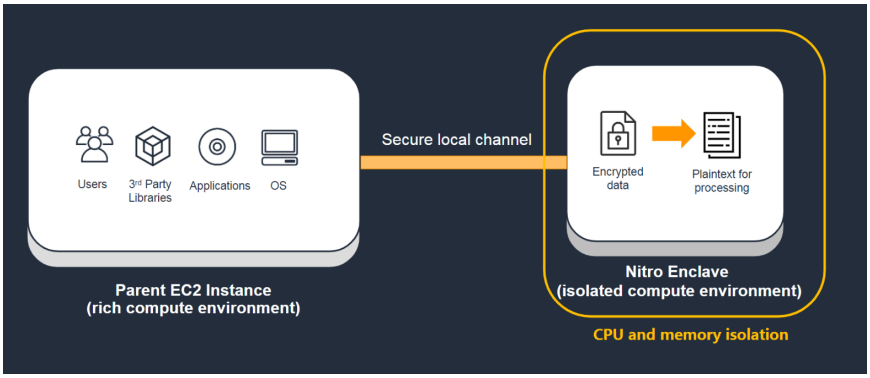
Step 2: Build the enclave image file ... 44
Step 3: Run the enclave ... 45
Step 4: Validate the enclave ... 46
Step 5: Terminate the enclave ... 47
Getting started: Using the virtio-vsock ... 48
Overview: Connect the parent instance with an enclave by using virtio-vsock ... 48
Example: Connect the parent instance and enclave with Python ... 50
Getting started: Integrating with AWS KMS ... 59
Communication overview ... 60
Integrate this pattern in your own application ... 61
Example: Decrypt a secret with AWS tooling ... 62
Working with multiple enclaves ... 66
Nitro Enclaves and Amazon EKS ... 68
Prerequisites ... 69
Step 1: Create a launch template ... 70
Step 2: Create Kubernetes cluster and node ... 72
Step 3: Install the Nitro Enclaves Kubernetes device plugin ... 74
Step 4: Prepare the image ... 76
Step 5: Deploy the application to the cluster ... 77
Cryptographic attestation ... 83
Integration with AWS KMS ... 83
Where to get an enclave's measurements ... 84
PCR0, PCR1, and PCR2 ... 85
PCR3 ... 86
PCR4 ... 86
PCR8 ... 87
How to get an enclave's attestation document ... 89
Using cryptographic attestation with AWS KMS ... 89
Secret data preparation ... 18
KMS key preparation ... 90
Getting started with cryptographic attestation ... 92
Verifying the root of trust ... 93
Attestation in the Nitro Enclaves world ... 93
The attestation document ... 93
Attestation document specification ... 94
Attestation document validation ... 95

COSE and CBOR ... 96
Semantical validity ... 97
Certificate validity ... 97
Certificate chain validity ... 97
AWS Certificate Manager for Nitro Enclaves ... 99
Pricing and billing ... 100
Considerations ... 100
Install ACM for Nitro Enclaves ... 100
Step 1: Create the ACM certificate ... 101
Step 2: Prepare the enclaves-enabled parent instance ... 102
Step 3: Prepare the IAM role ... 103
Step 4: Associate the role with the ACM certificate ... 104
Step 5: Grant the role permission to access the certificate and encryption key ... 105
Step 6: Attach the role to the instance ... 106
Step 7: Configure the web server to use ACM for Nitro Enclaves ... 107
Using multiple certificates ... 113
Update ACM for Nitro Enclaves ... 116
Uninstall ACM for Nitro Enclaves ... 116
Security ... 118
Shared responsibility ... 118
Amazon EC2 security ... 118
Enclave security ... 119
Logging API calls with AWS CloudTrail ... 119
Nitro Enclaves information in CloudTrail ... 120
Understanding Nitro Enclaves log file entries ... 121
Nitro Enclaves CLI ... 125
Install the CLI on Linux ... 125
Install the CLI on Windows ... 129
Install Nitro CLI ... 130
Uninstall the CLI on Linux ... 130
Uninstall the CLI on Windows ... 131
Nitro CLI Reference ... 131
nitro-cli build-enclave ... 132
nitro-cli run-enclave ... 135
nitro-cli describe-enclaves ... 142
nitro-cli console ... 145

nitro-cli describe-eif 146
nitro-cli sign-eif 147
nitro-cli pcr 149
nitro-cli terminate-enclave 151
Nitro Enclaves CLI error codes 153
Document history 161

What is Nitro Enclaves?

AWS Nitro Enclaves is an Amazon EC2 feature that allows you to create isolated execution environments, called *enclaves*, from Amazon EC2 instances. Enclaves are separate, hardened, and highly-constrained virtual machines. They provide only secure local socket connectivity with their parent instance. They have no persistent storage, interactive access, or external networking. Users cannot SSH into an enclave, and the data and applications inside the enclave cannot be accessed by the processes, applications, or users (root or admin) of the parent instance. Using Nitro Enclaves, you can secure your most sensitive data, such as personally identifiable information (PII), and your data processing applications.



> **Note**
>
> Nitro Enclaves is processor agnostic and it is supported on most Intel, AMD, and AWS Graviton-based Amazon EC2 instance types built on the AWS Nitro System.

Nitro Enclaves also supports an attestation feature, which allows you to verify an enclave's identity and ensure that only authorized code is running inside it. Nitro Enclaves is integrated with the AWS Key Management Service, which provides built-in support for attestation and enables you to prepare and protect your sensitive data for processing inside enclaves. Nitro Enclaves can also be used with other key management services.

Nitro Enclaves use the same Nitro Hypervisor technology that provides CPU and memory isolation for Amazon EC2 instances in order to isolate the vCPUs and memory for an enclave from a parent instance. The Nitro Hypervisor ensures that the parent instance has no access to the isolated vCPUs and memory of the enclave.

To learn more about creating your first enclave using a sample enclave application, see Getting started: Hello Enclaves sample application.

Topics

- Learn more
- Requirements
- Considerations
- Pricing
- Related services

Learn more

- To learn about the concepts used in Nitro Enclaves, see Nitro Enclaves concepts.
- To get started with your first enclave using a sample enclave application, see Getting started: Hello Enclaves sample application.
- To learn about using the AWS Nitro Enclaves CLI to manage the lifecycle of enclaves, see Nitro Enclaves Command Line Interface.
- To learn about developing custom enclave applications and the AWS Nitro Enclaves SDK, see Nitro Enclaves application development.
- To learn about multiple enclaves, see Working with multiple enclaves.

Requirements

Nitro Enclaves has the following requirements:

- **Parent instance requirements:**
  - The parent instance must use one of the following instance types and a Linux or Windows (2016 or later) operating system.

    General purpose

Instance family	Instance types
M5	All instance types, **except**: `m5.large` | `m5.metal`

Instance family	Instance types
M5a	All instance types, **except**: `m5a.large`
M5ad	All instance types, **except**: `m5ad.large`
M5d	All instance types, **except**: `m5d.large` | `m5d.metal`
M5dn	All instance types, **except**: `m5dn.large` | `m5dn.metal`
M5n	All instance types, **except**: `m5n.large` | `m5n.metal`
M5zn	All instance types, **except**: `m5zn.large` | `m5zn.metal`
M6a	All instance types, **except**: `m6a.large` | `m6a.metal`
M6g	All instance types, **except**: `m6g.medium` | `m6g.metal`
M6gd	All instance types, **except**: `m6gd.medium` | `m6gd.metal`
M6i	All instance types, **except**: `m6i.large` | `m6i.metal`
M6id	All instance types, **except**: `m6id.large` | `m6id.metal`
M6idn	All instance types, **except**: `m6idn.large` | `m6idn.metal`
M6in	All instance types, **except**: `m6in.large` | `m6in.metal`
M7a	All instance types, **except**: `m7a.medium` | `m7a.large` | `m7a.metal-48xl`
M7g	All instance types, **except**: `m7g.medium` | `m7g.metal`
M7gd	All instance types, **except**: `m7gd.medium` | `m7gd.metal`
M7i	All instance types, **except**: `m7i.large` | `m7i.metal-24xl` | `m7i.metal-48xl`
M8a	All instance types, **except**: `m8a.medium` | `m8a.metal-24xl` | `m8a.metal-48xl`

Instance family	Instance types
M8azn	All instance types, **except**: `m8azn.medium` | `m8azn.metal-12xl` | `m8azn.metal-24xl`
M8g	All instance types, **except**: `m8g.medium` | `m8g.metal-24xl` | `m8g.metal-48xl`
M8gb	All instance types, **except**: `m8gb.medium` | `m8gb.metal-24xl` | `m8gb.metal-48xl`
M8gd	All instance types, **except**: `m8gd.medium` | `m8gd.metal-24xl` | `m8gd.metal-48xl`
M8gn	All instance types, **except**: `m8gn.medium` | `m8gn.metal-24xl` | `m8gn.metal-48xl`
M8i	All instance types, **except**: `m8i.large` | `m8i.metal-48xl` | `m8i.metal-96xl`
M8id	All instance types, **except**: `m8id.large` | `m8id.metal-48xl` | `m8id.metal-96xl`
M8in	All instance types, **except**: `m8in.large` | `m8in.metal-48xl` | `m8in.metal-96xl`
M8idn	All instance types, **except**: `m8idn.large` | `m8idn.metal-48xl` | `m8idn.metal-96xl`
M8ine	All instance types, **except**: `m8ine.large`
M8ib	All instance types, **except**: `m8ib.large` | `m8ib.metal-48xl` | `m8ib.metal-96xl`
M8idb	All instance types, **except**: `m8idb.large` | `m8idb.metal-48xl` | `m8idb.metal-96xl`
M9g	All instance types, **except**: `m9g.medium` | `m9g.metal-48xl`

Instance family	Instance types
M9gd	All instance types, **except**: `m9gd.medium` | `m9gd.metal-48xl`

Compute optimized

Instance family	Exceptions
C5	All instance types, **except**: `c5.large` | `c5.metal`
C5a	All instance types, **except**: `c5a.large`
C5ad	All instance types, **except**: `c5ad.large`
C5d	All instance types, **except**: `c5d.large` | `c5d.metal`
C5n	All instance types, **except**: `c5n.large` | `c5n.metal`
C6a	All instance types, **except**: `c6a.large` | `c6a.metal`
C6g	All instance types, **except**: `c6g.medium` | `c6g.metal`
C6gd	All instance types, **except**: `c6gd.medium` | `c6gd.metal`
C6gn	All instance types, **except**: `c6gn.medium`
C6i	All instance types, **except**: `c6i.large` | `c6i.metal`
C6id	All instance types, **except**: `c6id.large` | `c6id.metal`
C6in	All instance types, **except**: `c6in.large` | `c6in.metal`
C7a	All instance types, **except**: `c7a.medium` | `c7a.large` | `c7a.metal-48xl`
C7g	All instance types, **except**: `c7g.medium` | `c7g.metal`

Instance family	Exceptions
C7gd	All instance types, **except**: `c7gd.medium` | `c7gd.metal`
C7i	All instance types, **except**: `c7i.large` | `c7i.metal-24xl` | `c7i.metal-48xl`
C8a	All instance types, **except**: `c8a.medium` | `c8a.metal-24xl` | `c8a.metal-48xl`
C8g	All instance types, **except**: `c8g.medium` | `c8g.metal-24xl` | `c8g.metal-48xl`
C8gb	All instance types, **except**: `c8gb.medium` | `c8gb.metal-24xl` | `c8gb.metal-48xl`
C8gd	All instance types, **except**: `c8gd.medium` | `c8gd.metal-24xl` | `c8gd.metal-48xl`
C8gn	All instance types, **except**: `c8gn.medium` | `c8gn.metal-24xl` | `c8gn.metal-48xl`
C8i	All instance types, **except**: `c8i.large` | `c8i.metal-48xl` | `c8i.metal-96xl`
C8id	All instance types, **except**: `c8id.large` | `c8id.metal-48xl` | `c8id.metal-96xl`
C8in	All instance types, **except**: `c8in.large` | `c8in.metal-48xl` | `c8in.metal-96xl`
C8ine	All instance types, **except**: `c8ine.large`
C8ib	All instance types, **except**: `c8ib.large` | `c8ib.metal-48xl` | `c8ib.metal-96xl`
C9g	All instance types, **except**: `c9g.medium` | `c9g.metal-48xl`
C9gd	All instance types, **except**: `c9gd.medium` | `c9gd.metal-48xl`

Memory optimized

Instance family	Instance types
R5	All instance types, **except**: `r5.large` | `r5.metal`
R5a	All instance types, **except**: `r5a.large`
R5ad	All instance types, **except**: `r5ad.large`
R5b	All instance types, **except**: `r5b.large` | `r5b.metal`
R5d	All instance types, **except**: `r5d.large` | `r5d.metal`
R5dn	All instance types, **except**: `r5dn.large` | `r5dn.metal`
R5n	All instance types, **except**: `r5n.large` | `r5n.metal`
R6a	All instance types, **except**: `r6a.large` | `r6a.metal`
R6g	All instance types, **except**: `r6g.medium` | `r6g.metal`
R6gd	All instance types, **except**: `r6gd.medium` | `r6gd.metal`
R6i	All instance types, **except**: `r6i.large` | `r6i.metal`
R6id	All instance types, **except**: `r6id.large` | `r6id.metal`
R6idn	All instance types, **except**: `r6idn.large` | `r6idn.metal`
R6in	All instance types, **except**: `r6in.large` | `r6in.metal`
R7a	All instance types, **except**: `r7a.medium` | `r7a.large` | `r7a.metal-48xl`
R7g	All instance types, **except**: `r7g.medium` | `r7g.metal`
R7gd	All instance types, **except**: `r7gd.medium` | `r7gd.metal`

Instance family	Instance types
R7i	All instance types, **except**: `r7i.large` | `r7i.metal-24xl` | `r7i.metal-48xl`
R7iz	All instance types, **except**: `r7iz.large` | `r7iz.metal-16xl` | `r7iz.metal-32xl`
R8a	All instance types, **except**: `r8a.medium` | `r8a.metal-24xl` | `r8a.metal-48xl`
R8g	All instance types, **except**: `r8g.medium` | `r8g.metal-24xl` | `r8g.metal-48xl`
R8gb	All instance types, **except**: `r8gb.medium` | `r8gb.metal-24xl` | `r8gb.metal-48xl`
R8gd	All instance types, **except**: `r8gd.medium` | `r8gd.metal-24xl` | `r8gd.metal-48xl`
R8gn	All instance types, **except**: `r8gn.medium` | `r8gn.metal-24xl` | `r8gn.metal-48xl`
R8i	All instance types, **except**: `r8i.large` | `r8i.metal-48xl` | `r8i.metal-96xl`
R8id	All instance types, **except**: `r8id.large` | `r8id.metal-48xl` | `r8id.metal-96xl`
R8in	All instance types, **except**: `r8in.large` | `r8in.metal-48xl` | `r8in.metal-96xl`
R8idn	All instance types, **except**: `r8idn.large` | `r8idn.metal-48xl` | `r8idn.metal-96xl`
R8ib	All instance types, **except**: `r8ib.large` | `r8ib.metal-48xl` | `r8ib.metal-96xl`

Instance family	Instance types
R8idb	All instance types, **except**: `r8idb.large` | `r8idb.metal-48xl` | `r8idb.metal-96xl`
R9g	All instance types, **except**: `r9g.medium` | `r9g.metal-48xl`
R9gd	All instance types, **except**: `r9gd.medium` | `r9gd.metal-48xl`
X2gd	All instance types, **except**: `x2gd.medium` | `x2gd.metal`
X2idn	All instance types, **except**: `x2idn.metal`
X2iedn	All instance types, **except**: `x2iedn.metal`
X2iezn	All instance types, **except**: `x2iezn.metal`
X8g	All instance types, **except**: `x8g.medium` | `x8g.metal-24xl` | `x8g.metal-48xl`
X8aedz	All instance types, **except**: `x8aedz.metal-12xl` | `x8aedz.metal-24xl`
X8i	All instance types, **except**: `x8i.large` | `x8i.metal-48xl` | `x8i.metal-96xl`
z1d	All instance types, **except**: `z1d.large` | `z1d.metal`

Storage optimized

Instance family	Instance types
D3	All instance types.
D3en	All instance types.
I3en	All instance types, **except**: `i3en.large` | `i3en.metal`

Instance family	Instance types
I4g	All instance types.
I4i	All instance types, **except**: `i4i.large` | `i4i.metal`
I7i	All instance types, **except**: `i7i.large` | `i7i.metal-24xl` | `i7i.metal-48xl`
I7ie	All instance types, **except**: `i7ie.large` | `i7ie.metal-24xl` | `i7ie.metal-48xl`
I8g	All instance types, **except**: `i8g.metal-24xl` | `i8g.metal-48xl`
I8ge	All instance types, **except**: `i8ge.metal-24xl` | `i8ge.metal-48xl`

Accelerated computing

Instance family	Instance types
DL1	All instance types.
DL2q	All instance types.
F2	All instance types.
G4dn	All instance types, **except**: `g4dn.metal`
G5	All instance types.
G6	All instance types.
G6e	All instance types.
G6f	All instance types, **except**: `g6f.large`
Gr6	All instance types.

Instance family	Instance types
Gr6f	All instance types.
G7	All instance types.
G7e	All instance types.
Inf1	All instance types.
Inf2	All instance types.
P4d	All instance types.
P4de	All instance types.
P5	All instance types.
P5e	All instance types.
P5en	All instance types.
P6-B300	All instance types.
P6e-GB200	All instance types.
Trn2	All instance types.
Trn2u	All instance types.

- **Enclave requirements:**
  - The enclave must run a Linux operating system.

Considerations

Keep the following in mind when using Nitro Enclaves:

- Nitro Enclaves is supported in all AWS Regions, including the AWS GovCloud (US) Regions.

- You can create up to four individual enclaves per parent instance.
- Enclaves can communicate only with the parent instance. Enclaves running on the same or different parent instances cannot communicate with each other.
- Enclaves are active only while their parent instance is in the `running` state. If the parent instance is stopped or terminated, its enclaves are terminated.
- You cannot enable hibernation and enclaves on the same instance.
- Nitro Enclaves is not supported on Outposts.
- Nitro Enclaves is not supported in Local Zones or Wavelength Zones.

Pricing

There are no additional charges for using Nitro Enclaves. You are billed the standard charges for the Amazon EC2 instance and for the other AWS services that you use.

Related services

Nitro Enclaves is integrated with the following AWS services:

AWS Key Management Service

AWS Key Management Service (KMS) makes it easy for you to create and manage cryptographic keys and control their use across a wide range of AWS services and in your applications. Nitro Enclaves integrates with AWS KMS and it allows you to perform selected KMS operations from the enclave using the AWS Nitro Enclaves SDK. These operations can be tied to the cryptographic attestation process of Nitro Enclaves by setting a AWS KMS key policy to ensure that the operation works only when the measurements of the enclave match the KMS key policy. For more information, see AWS KMS condition keys for Nitro Enclaves in the *AWS Key Management Service Developer Guide*.

AWS Certificate Manager

AWS Certificate Manager (ACM) is a service that lets you easily provision, manage, and deploy public and private Secure Sockets Layer/Transport Layer Security (SSL/TLS) certificates for use with AWS services and your internal connected resources. SSL/TLS certificates are used to secure network communications and to establish the identity of websites over the internet, as well as resources on private networks. ACM removes the time-consuming manual process

of purchasing, uploading, and renewing SSL/TLS certificates. For more information, see AWS Certificate Manager for Nitro Enclaves.

Nitro Enclaves concepts

The following concepts are important to your understanding and use of AWS Nitro Enclaves.

Concepts

- Enclave
- Enclave ID
- Parent instance
- Enclave image file
- AWS Nitro Enclaves CLI
- AWS Nitro Enclaves SDK
- Cryptographic attestation
- Attestation document
- Platform configuration registers
- KMS proxy
- Vsock socket

Enclave

An enclave is a virtual machine with its own kernel, memory, and CPUs. It is created by partitioning memory and vCPUs from a Nitro-based *parent instance*. An enclave has no external network connectivity, and no persistent storage. The enclave's isolated vCPUs and memory can't be accessed by the processes, applications, kernel, or users of the parent instance.

Enclave ID

An enclave ID is a unique identifier across AWS. It consists of the *parent instance* ID and an identifier for each enclave created by the instance. For example, an enclave created by a parent instance with an ID of `i-1234567890abcdef0` could have an enclave ID of `i-1234567890abcdef0-enc9876543210abcde`.

Parent instance

The parent instance is the Amazon EC2 instance that is used to *allocate* CPU cores and memory to the enclave. The resources are allocated to the enclave for the duration of its lifetime. The parent instance is the only instance that can communicate with its enclave.

Enclave image file

An enclave image file (`.eif`) includes a Linux operating system, libraries, and enclave applications that will be booted into an enclave when it is launched.

AWS Nitro Enclaves CLI

The AWS Nitro Enclaves CLI (Nitro CLI) is a command line tool that is used to create, manage, and terminate enclaves. The Nitro CLI must be installed and used on the *parent instance*. For more information, see Nitro Enclaves Command Line Interface.

AWS Nitro Enclaves SDK

The AWS Nitro Enclaves SDK is an open-source library that you can use to develop enclave applications, or to update existing applications to run in an enclave. The SDKs also integrate with AWS KMS and provide built-in support for *cryptographic attestation* and other cryptographic operations. For more information, see Nitro Enclaves application development.

Cryptographic attestation

Cryptographic attestation is the process that an enclave uses to prove its identity and build trust with an external service. Attestation is accomplished using a signed *attestation document* that is generated by the Nitro Hypervisor. The values in an enclave's attestation document can be used as a condition for an authorization decision by an external party. AWS KMS allows you to use attestation document values in conditions keys to grant access to specific cryptographic operations. For more information, see Cryptographic attestation.

Attestation document

An attestation document is generated and signed by the Nitro Hypervisor. It contains information about the enclave, including *platform configuration registers* (PCRs), a cryptographic nonce, and

additional information that you can define. It can be used by an external service to verify the identity of an enclave and to establish trust. You can use the attestation document to build your own *cryptographic attestation* mechanisms, or you can use it with AWS KMS, which provides built-in support for authorizing cryptographic requests based on values in the attestation document. For more information, see Cryptographic attestation.

Platform configuration registers

Platform configuration registers (PCRs) are cryptographic measurements that are unique to an enclave. Some PCRs are automatically generated when the enclave is created, and they can be used to verify that no changes have been made to the enclave since it was created. You can also manually create additional PCRs that can be used to ensure that the enclave is running on the instance on which you expect it to run. PCRs are included in the *attestation document* that is generated by the Nitro Hypervisor. You can use PCRs to create condition keys for AWS KMS keys. For more information, see Where to get an enclave's measurements.

KMS proxy

The KMS proxy is used by enclaves running in a parent instance to call AWS KMS through the parent instance's networking. The proxy ships with Nitro CLI and it runs on the parent instance. The proxy is required only if you use AWS KMS as your key management service and you perform AWS KMS operations (`kms-decrypt`, `kms-generate-data-key`, and `kms-generate-random`) using the Nitro Enclaves SDK. Sessions with KMS are established logically between AWS KMS and the enclave itself, and all session traffic is protected from the parent instance and from other enclaves.

Vsock socket

Vsock is a local communication channel between a parent instance and its enclaves. It is the only channel of communication that an enclave can use to interact with external services. An enclave launched from a parent instance will share the vsock with other enclaves launched from the same parent instance. An enclave's vsock address is defined by a context identifier (CID) that you can set when launching an enclave. Each enclave running on a parent instance gets a unique CID. The CID used by the parent instance is always 3.

On Linux, Vsock utilizes standard, well-defined POSIX socket APIs, such as `connect`, `listen`, and `accept`. On Windows, the Vsock uses the standard Windows sockets (Winsock2) API.

Enclave workflow overview

The following topic explains some of the roles and basic workflows of AWS Nitro Enclaves, using AWS KMS as the key management service, and Amazon S3 as the data storage service.

Topics

- Involved parties
- Data and environment preparation
- Attestation and data decryption
- Nitro Enclaves application development
- Building an enclave image file
- Creating an enclave

Involved parties

A typical Nitro Enclaves use case involves multiple parties. Each party is responsible for completing certain tasks to ensure that the enclave is operational. A typical use case includes the following parties:

- **Data owner**—Owns the AWS KMS key and the secret data. The owner is responsible for creating the KMS key in AWS KMS, encrypting the secret data, and making the encrypted data and the encrypted data key available.
- **Parent instance administrator**—Owns the parent instance and manages the enclave's lifecycle. This party launches the parent instance and then creates the enclave using the enclave image file or Docker image, which is provided by the application developer. The parent instance administrator should not have permission to perform cryptographic actions using the KMS key, and they should not have permission to change the KMS key policy. The parent instance however, will need permissions to call `kms-decrypt` using the KMS key, but the request will only succeed if it is made from inside the enclave, and it includes values that match the condition keys in the KMS key policy.
- **Application developer**—Develops the applications that run in the enclave and on the parent instance. The developer packages the application into an enclave image file or Docker image and provides it to the parent instance administrator, who uses it to create the enclave. The application developer might also develop applications that run on the parent instance itself.

Data and environment preparation

The following section provides an overview of the data encryption process, attestation set up, and enclave creation process.

1. Create a AWS KMS key in AWS KMS. For more information, see Creating Keys in the *AWS Key Management Service Developer Guide*.
2. Generate a plaintext and encrypted data key using the KMS key. For more information, see generate-data-key in the *AWS KMS AWS CLI Command Reference*.
3. Encrypt the secret data under the KMS key using the plaintext data key and a client-side cryptographic library, such as the AWS Encryption SDK. For more information, see Encrypt data with a data key in the *AWS Key Management Service Developer Guide*. You will need to modify the key policy of the KMS key to give the IAM principal you're using in your client permission to call the GenerateDataKey API action
4. Upload the encrypted secret data and the encrypted data key to a storage location, such as Amazon S3. If you're using the AWS Encryption SDK, the encrypted data key is automatically included in the header of the encrypted message.
5. Inspect the enclave application. This could be a pre-packaged enclave application, an existing application that has been refactored to run in an enclave, or a brand new enclave application.
6. If you are satisfied with the security properties of the application, package the application into a Docker file, and then use the AWS Nitro Enclaves CLI to convert the Docker file into an enclave image file. For more information, see Building an enclave image file.

   Make a note of the platform configuration registers (PCRs) that are generated when the enclave image is created.
7. Use the PCRs to add attestation-based condition keys to the KMS key that you used to encrypt the data. For more information, see Cryptographic attestation.
8. Launch the enclave-enabled parent instance and boot the enclave using the enclave image. For more information, see Creating an enclave.

Attestation and data decryption

The following section provides an overview of the attestation and data decryption process.

1. Download the encrypted data and the encrypted data key from Amazon S3 to the parent instance.

2. Transfer the encrypted data and the encrypted data key to the enclave over the vsock socket.
3. Call the `kms-decrypt` Nitro Enclaves SDK, which sends the encrypted data key and the attestation document to AWS KMS. The attestation document includes the enclave's PCRs and public key. The request is sent over the vsock socket to the parent instance, and the parent instance forwards the request to AWS KMS via the AWS KMS proxy.
4. AWS KMS receives the request and verifies that the attached attestation document is signed by the Nitro Hypervisor. AWS KMS then compares the PCRs in the attestation document with the PCRs in the condition keys in the policy of the requested KMS key.
5. If the PCRs in the attestation document match the PCRs in the condition keys of the KMS key policy, AWS KMS encrypts the plaintext data key with the enclave's public key from the attestation document.
6. The encrypted plaintext data key is returned to the parent instance over the KMS proxy, and the parent instance sends it to the enclave over the vsock socket.
7. The encrypted plaintext data key is decrypted using the enclave's private key.
8. The plaintext data key is used to decrypt the encrypted data.
9. The data is now ready to be processed inside the enclave.

Nitro Enclaves application development

An enclave application is an application that is designed and developed to run inside the isolated enclave environment. An enclave application typically consists of at least two components:

- An application that runs on the parent instance
- An application that runs inside the enclave

Due to the isolated environment of the enclave, the only channel of communication between applications that are running on the instance and applications that are running in the enclave is the vsock socket.

Topics

- Nitro Enclaves Developer AMI
- Nitro Enclaves SDK
- Nitro Enclaves application development on Linux instances
- Nitro Enclaves Application development on Windows instances

Nitro Enclaves Developer AMI

AWS provides a Nitro Enclaves Developer AMI that contains the tools and components needed to develop enclave applications and to build enclave image files. It also contains samples applications, such as hello-enclave, vsock_sample and kmstool, to demonstrate how to use and develop your own enclave applications. For more information, see AWS Nitro Enclaves Developer AMI.

Nitro Enclaves SDK

The Nitro Enclaves SDK is a set of open-source libraries that you can use to develop your enclave applications. The SDKs also integrate with AWS KMS and provide built-in support for attestation and cryptographic operations. For more information about the SDKs and how to use them, see the Nitro Enclaves SDK Github repository.

Nitro Enclaves application development on Linux instances

This section provides information for Nitro Enclaves application development on Linux instances.

Getting started with the vsock: Vsock tutorial

> **Important**
>
> The vsock sample application is supported on Linux instances only.

The vsock sample application is a simple client-server application that exchanges information between the parent instance and the enclave using the vsock socket.

The vsock sample application includes a client application and a server application. The client application runs on the parent instance, while the server application runs in the enclave. The client application sends a simple text message over the vsock to the server application. The server application listens to the vsock and prints the message to the console.

The vsock sample application is available in both Rust and Python. This tutorial shows you how to set up and run the Rust vsock sample application. For more information about setting up and running the Python vsock sample application, see the AWS Nitro Enclaves samples GitHub repository.

> **Note**
>
> The application source is also freely available from the AWS Nitro Enclaves samples GitHub repository. You can use the application source as a reference for building your own applications.

Prerequisites

Ensure the following prerequisites are met to configure and test the sample application.

- To test the sample application using the Nitro CLI, configure an enclave-enabled parent instance as detailed in Step 1: Prepare the enclave-enabled parent instance. This is the only step required from the getting started guide required to create the sample application.
- To clone the sample repository from GitHub, install a Git client on the parent instance. For more information, see Install Git in the GitHub documentation.
- To compile the Rust vsock sample application, you must have Cargo, Rust's build system and package manager installed. You must also add the `x86_64-unknown-linux-musl target` or `aarch64-unknown-linux-musl target`. To install and configure Rust, use the following commands.

```
$ curl --proto '=https' --tlsv1.2 https://sh.rustup.rs -sSf | sh
```

> **Important**
>
> You must disconnect from the instance and then reconnect before running the following commands.

After you reconnect to the instance, determine the architecture of the operating system to configure and test the sample application. The architecture will be either `x86_64` or `aarch64`. Run the following command to display the architecture of the operating system.

```
echo $(uname -m)
```

Run the following commands to finish installing and configuring Rust.

```
$ rustup target add x86_64-unknown-linux-musl
```

```
$ sudo yum -y install gcc
```

To try the vsock sample application

1. Download the application source and navigate into the directory.

```
$ git clone https://github.com/aws/aws-nitro-enclaves-samples.git
```

```
$ cd aws-nitro-enclaves-samples/vsock_sample/rs
```

2. Compile the application code using Cargo.

```
$ cargo build --target=x86_64-unknown-linux-musl --release
```

The compiled binary is located in `vsock_sample/rs/target/x86_64-unknown-linux-musl/release/vsock-sample`.

3. Navigate two levels up.

```
$ cd ../..
```

4. Create a new file named `Dockerfile` and then add the following.

```
# start the Docker image from the Alpine Linux distribution
FROM alpine:latest
# copy the vsock-sample binary to the Docker file
COPY vsock_sample/rs/target/x86_64-unknown-linux-musl/release/vsock-sample .
# start the server application inside the enclave
CMD ./vsock-sample server --port 5005
```

5. Convert the Docker file to an enclave image file.

```
$ nitro-cli build-enclave --docker-dir ./ --docker-uri vsock-sample-server --
output-file vsock_sample.eif
```

6. Boot the enclave using the enclave image file. You need to access the enclave console to see the server application output, so you must include the `--debug-mode` option.

```
$ nitro-cli run-enclave --eif-path vsock_sample.eif --cpu-count 2 --enclave-cid 6
 --memory 256 --debug-mode
```

   Make a note of the enclave ID, because you'll need this to connect to the enclave console.

7. Open the enclave console. The console provides a view of what's happening on the server side of the application.

```
$ nitro-cli console --enclave-id enclave_id
```

8. Open an SSH terminal window for the parent instance. You'll use this terminal to run the client application.
9. In the parent instance terminal, run the client application. When you start the client application, it automatically sends some text over the vsock to the server application running in the enclave. Watch the enclave console terminal for the output.

```
$ ./aws-nitro-enclaves-samples/vsock_sample/rs/target/x86_64-unknown-linux-musl/
release/vsock-sample client --cid 6 --port 5005
```

10. When the server application receives the text over the vsock, it prints the text to the console.

```
$ [    0.127079] Freeing unused kernel memory: 476K
[    0.127631] nsm: loading out-of-tree module taints kernel.
[    0.128055] nsm: module verification failed: signature and/or required key
 missing - tainting kernel
[    0.154010] random: vsock-sample: uninitialized urandom read (16 bytes read)
Hello, world!
```

Now that you understand how the sample application works, download and customize the source code to suit your use case.

Nitro Enclaves Application development on Windows instances

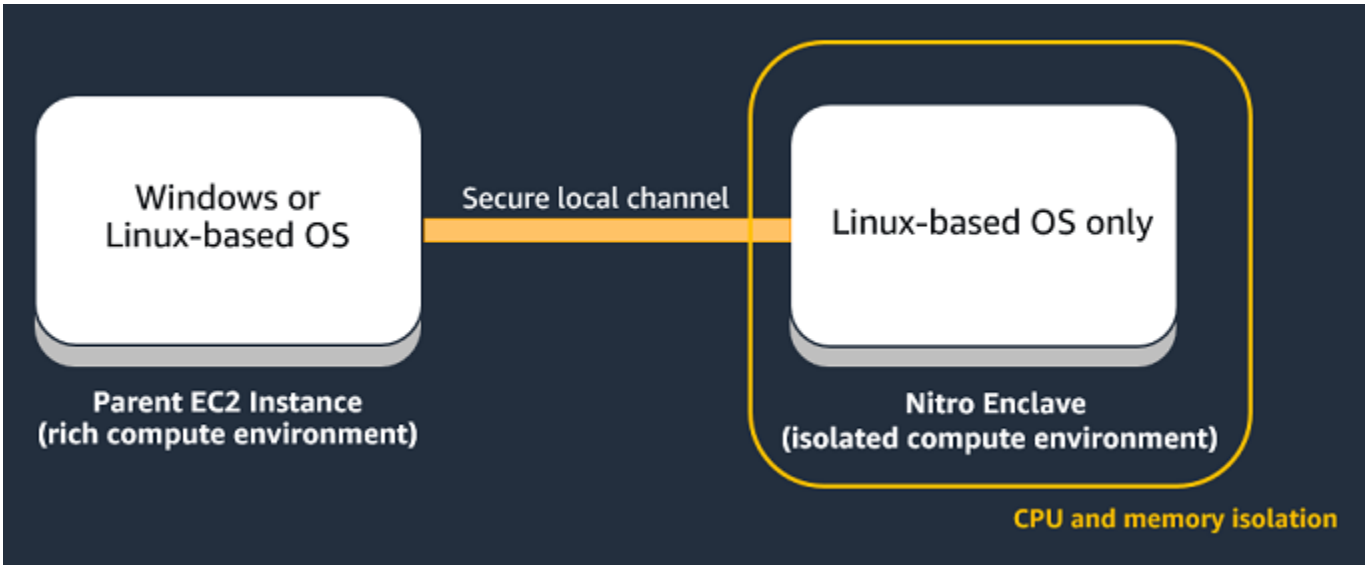
This section provides information for Nitro Enclaves application development on Windows instances.

Topics

- Considerations for using Nitro Enclaves on a Windows parent instance
- Nitro Enclaves for Windows release notes
- Subscribe to notifications of new versions
- Working with the vsock socket in Windows

Considerations for using Nitro Enclaves on a Windows parent instance

The EC2 parent instance and the enclaves operate as separate virtual machines. This means that each of them (the parent instance and all of its enclaves) must run its own operating system. The parent instance, supports both Linux and Windows (2016 and later) operating systems. However, the enclaves support only operating systems that support the Linux boot protocol. This means that even if you have a Windows parent instance, you must run a Linux environment inside your enclaves.



This also means that you must use a Linux-based instance to build your enclave image file (`.eif`).

Keep the following in mind when using a Windows parent instance.

- Only Windows 2016 and later is supported on the parent instance.
- You must run a Linux-based environment inside the enclave.
- The Hello enclaves sample application is supported on Windows parent instances, but the enclave image file (`.eif`) must be built on a Linux instance. For more information, see Getting started: Hello Enclaves sample application.

- The KMS Tool sample application is supported on Windows parent instances, but the enclave image file (`.eif`) must be built on a Linux instance. For more information, see Getting started with cryptographic attestation using the KMS Tool sample application.
- On Windows, the vsock uses the standard Windows sockets (Winsock2) API. For more information, see Working with the vsock socket in Windows.
- AWS Certificate Manager for Nitro Enclaves is not supported with Windows parent instances.
- To use the AWS Nitro Enclaves CLI software on your parent instance, you must install the **AWSNitroEnclavesWindows** package using AWS Systems Manager Distributor. For more information, see Install the Nitro Enclaves CLI on Windows.
- The `nitro-cli build-enclave` command is not supported on Windows parent instances. For more information, see nitro-cli build-enclave.

Nitro Enclaves for Windows release notes

This section describes Nitro Enclaves (for Windows) features, improvements, and bug fixes by release date.

Release date	version	Updates and bug fixes
July 24, 2024	1.2.3	The release updated the Nitro Enclaves for Windows installer to use WiX Toolset v5.
October 18, 2023	1.2.2	The release improved installat ion of Nitro Enclaves for Windows and deprecated support for Windows Server 2012 R2.
March 27, 2023	1.2.1	The release fixed a bug related to terminating multiple enclaves. This is the last version to support Windows Server 2012 R2.
May 4, 2022	1.2.0	

Release date	version	Updates and bug fixes
		The release added the following commands, arguments, and output for Nitro CLI: • Added `pcr` and `describe-eif` commands. • Added `--enclave-name` argument for `run-enclave` , `console`, and `terminate-enclave` commands. • Added `--disconnect-timeout` argument for `console` command. • Added `--config` argument and `--attach-console` flag to `run-enclave` command • Updated `describe-enclaves` and `run-enclave` commands to display `EnclaveName` . • Added `--metadata` flag to `describe-enclaves` command.

Release date	version	Updates and bug fixes
		The release added the following bug fixes and enhancements: • Improved Nitro CLI error messages. • Fixed bugs in vsock `select()` when it blocks or returns certain calls. • Fixed bug in vsock `shutdown()` on non blocking sockets, which can result in connection reset errors.

Release date	version	Updates and bug fixes
July 27, 2021	1.1.0	The release added the following bug fixes and enhancements: • Improved vsock error codes and Nitro CLI error messages. • Improved vsock driver stability when enabling and disabling the vsock device. • Improved Nitro CLI efficiency during failed enclave startups. • Improved vsock-proxy stability. • Fixed the bug that prevented installation using SSM Distributor after a failed installation attempt.
April 27, 2021	1.0	Initial release of Nitro Enclaves for Windows.

Subscribe to notifications of new versions

Amazon SNS can notify you when new versions of Nitro Enclaves for Windows are released. Use one of the following procedures to subscribe to these notifications.

Amazon SNS console

To subscribe to notifications using the Amazon SNS console

1. Open the Amazon SNS console at https://console.aws.amazon.com/sns/v3/home.
2. In the navigation bar, change the Region to **US West (Oregon)**, if necessary. You must select this Region because the SNS notifications that you are subscribing to are in this Region.
3. In the navigation pane, choose **Subscriptions**.
4. Choose **Create subscription**.
5. In the **Create subscription** dialog box, do the following:
   a. For **Topic ARN**, enter `arn:aws:sns:us-west-2:404587003957:aws-nitro-enclaves-windows`.
   b. For **Protocol**, choose `Email`.
   c. For **Endpoint**, type an email address that you can use to receive the notifications.
   d. Choose **Create subscription**.
6. You'll receive a confirmation email. Open the email and follow the directions to complete your subscription.

AWS Tools for PowerShell Core

To subscribe to notifications using the Tools for Windows PowerShell

Use the following command.

```
C:\> Connect-SNSNotification -TopicArn 'arn:aws:sns:us-west-2:404587003957:aws-
nitro-enclaves-windows' -Protocol email -Region us-west-2 -
Endpoint 'your_email_address'
```

AWS Command Line Interface

To subscribe to notifications using the AWS CLI

Use the following command.

```
C:\> aws sns subscribe \
```

```
--topic-arn arn:aws:sns:us-west-2:404587003957:aws-nitro-enclaves-windows \
--protocol email \
--notification-endpoint your_email_address
```

If you no longer want to receive these notifications, use the following procedure to unsubscribe.

To unsubscribe to notifications using the Amazon SNS console

1. Open the Amazon SNS console at https://console.aws.amazon.com/sns/v3/home.
2. In the navigation bar, change the Region to **US West (Oregon)**.
3. In the navigation pane, choose **Subscriptions**.
4. Select the check box for the subscription and then choose **Delete**. When prompted for confirmation, choose **Delete**.

Working with the vsock socket in Windows

This topic provides information that is specific to working with the vsock socket on Windows instances.

Topics

- Terminology
- AWS vsock socket implementation
- Using the Winsock2 functions with vsock sockets
- Unsupported Winsock2 functions
- Known issues

Terminology

Service Provider Interface

The Service Provider Interface (SPI) is a library registered with the Windows Sockets 2 (Winsock2) API to support a new address family for the vsock socket. The vsock SPI is available in a 64-bit version only. Only 64-bit applications can use vsock sockets.

Port

The port component of an address. This is a 32-bit unsigned value.

Local address

The address of a vsock socket on the host on which the application is running. The address includes a context identifier (CID) and a port. The CID and port value pairs are concatenated with a `'.'` when written as a string. For example, a host with CID of `3` that listens on port `1234` has a listening address of `3.1234`.

Peer

A host that this host is communicating with over the vsock socket.

Remote address

The address of the vsock socket of the peer. The address includes a context identifier (CID) and a port. The CID and port value pairs are concatenated with a `'.'` when written as a string. For example, a host with CID of `3` that listens on port `1234` has a listening address of `3.1234`.

AWS vsock socket implementation

The following are considerations for vsock socket implementation using Winsock2.

Topics

- Build-time dependencies
- Runtime
- Loopback support

Build-time dependencies

Some value definitions are required to create and interact with vsock sockets. These include the definitions of `AF_VSOCK`, `sockaddr_vm`, and some reserved values for CIDs and ports. It is recommended that you include these definitions by including the `VirtioVsock.h` header in your code. For more information, about the header, see the Nitro Enclaves SDK Github repository.

Runtime

To create a Winsock2 socket with the `AF_VSOCK` address family, the vsock SPI must be registered with Winsock2. The vsock SPI is registered during the AWS Nitro Enclaves installation. Currently, the vsock SPI is available in a 64-bit version and supports only 64-bit applications. For more information about installing AWS Nitro Enclaves on a Windows instance, see Install Nitro CLI.

Loopback support

Loopback is not supported with vsock sockets. Attempts to `connect()` to a CID that belongs to the same host could result in an error.

Using the Winsock2 functions with vsock sockets

This section highlights differences between the Winsock2 functions and the AWS implementation for the vsock SPI.

> **Note**
>
> Functions not listed below follow the Winsock2 implementation and behave as described in the Winsock2 API documentation without any AWS specific nuances. For a list of the unsupported Winsock2 functions, see Unsupported Winsock2 functions.

Topics

- WSAAccept()/accept()
- WSAAddressToString()
- WSABind()/bind()
- WSAConnect()/connect()
- WSAEventSelect()
- WSAGetPeerName()
- WSAGetSockName()
- WSAGetSockOpt()/getsockopt()
- WSAIoctl()/ioctlsocket()
- WSAListen()/listen()
- WSASend()/send()
- WSASetSockOpt()/setsockopt()
- WSASocket()/socket()
- WSAStringToAddress()
- WSARecv()/recv()

WSAAccept()/accept()

If a vsock transport reset or device disable event occurs after receiving a connection request, but before `accept()` is called, `accept()` returns an invalid socket and `WSAGetLastError()` returns the value `WSAECONNRESET`.

WSAAddressToString()

Converts `sockaddr_vm` to a string in the `CID.Port` format.

WSABind()/bind()

To create a connection using a specific local port, you must call `bind()` with a valid local CID and the desired local port before calling `connect()`. An enclave-enabled Amazon EC2 instance is always assigned local CID of `3`. A socket bound to `SOCKADDR_VM_CID_ANY` can only be used for listening and cannot be used with `connect()`. `SO_REUSEADDR` and `SO_EXCLUSIVEADDRUSE` are not configurable. AWS vsock sockets behave as if `SO_EXCLUSIVEADDRUSE` is enabled for all sockets. That is, if any socket is bound to a local `CID.port` pair, no other socket can bind to that same local `CID.port` except as an `accept()` from a listening socket that is bound to `SOCKADDR_VM_CID_ANY.port` or `CID.port`. Additionally, sockets cannot be bound to `SOCKADDR_VM_CID_ANY.port` when any other socket on the host is bound to an address with the same local port value and any CID.

WSAConnect()/connect()

Outgoing connection requests have a non-configurable `1` second timeout before the peer responds with a connection acceptance packet. When using `WSAConnect()`, caller data and callee data are not supported. Specifying caller data results in an error and specifying callee data returns a length of `0`. QOS options are also not supported and return an error if specified.

WSAEventSelect()

`FD_OOB`, `FD_QOS`, `FD_GROUP_QOS`, `FD_ROUTING_INTERFACE_CHANGE`, and `FD_ADDRESS_LIST_CHANGE` will never be signaled in the current implementation. However, they do not return an error if specified.

WSAGetPeerName()

Gets the peer's socket address as a `sockaddr_vm`.

WSAGetSockName()

Gets the local socket address as a `sockaddr_vm`.

WSAGetSockOpt()/getsockopt()

Only the following `optname` parameters are supported:

- `SO_LINGER`
- `SO_DONTLINGER`
- `SO_RCVBUF`
- `SO_ACCEPTCONN`
- `SO_PROTOCOL_INFOW`
- `SO_TYPE`

For more information, see getsockopt function on the Windows app developer documentation website.

WSAIoctl()/ioctlsocket()

Only the following `ioctls` are supported:

- `FIONBIO`
- `FIONREAD`

For more information, see ioctlsocket function on the Windows app developer documentation website.

WSAListen()/listen()

Setting a backlog size of `0` or less sets the backlog size to `0`. Setting the backlog size to a value greater than the implementation-specific maximum backlog size, which is currently `2048`, sets the backlog size to the implementation-specific maximum backlog size. Reducing the backlog size while connection requests exist on a listening socket rejects some of the connection requests until the number of connections is equal to, or less than, the new backlog size.

WSASend()/send()

No flags are supported for these functions. The flag values must be set to `0`. If you specify a different value, an error is returned.

WSASetSockOpt()/setsockopt()

This function follows the Winsock2 implementation. However, only the following options are supported:

- `SO_LINGER`
- `SO_DONTLINGER`
- `SO_RCVBUF`

`SO_RCVBUF` has a minimum value of `4096` bytes and a maximum value of 2 MB. Requested buffer sizes are rounded down to a power of 2, or to 2 MB if the value is greater than 2 MB. Received buffer size defaults to 256 KB.

For more information, see ioctlsocket function on the Windows app developer documentation website.

WSASocket()/socket()

This function returns a new `SOCKET`. With the AWS vsock SPI, this `SOCKET` is also a `HANDLE` that allows you to call functions, such as `ReadFile` and `WriteFile` directly on the `SOCKET`.

This function must be called with `af = AF_VSOCK` and `type = SOCK_STREAM`. Only the `WSA_FLAG_OVERLAPPED` flag is supported when calling `WSASocket()`, which allows overlapped IO on the `SOCKET` that is returned. If `socket()` is called, the `WSA_FLAG_OVERLAPPED` flag is set. For more information about overlapped creation of sockets, see socket function on the Windows app developer documentation website.

WSAStringToAddress()

Converts a string in the format of `CID.Port` to a `sockaddr_vm`.

WSARecv()/recv()

Only the `MSG_PEEK` flag is supported for this function.

Unsupported Winsock2 functions

The following Winsock2 functions are not supported with AWS vsock sockets.

- `WSACancelBlockingCall()`
- `WSAAsyncSelect()`
- `WSAGetQosByName()`
- `WSAJoinLeaf()`
- `WSARecvDisconnect()`
- `WSASendDisconnect()`
- `WSARecvFrom()`
- `WSASendTo()`

Known issues

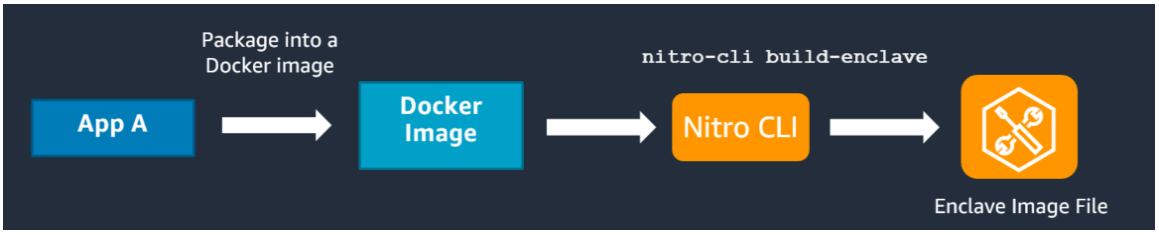
Some IOs cannot be canceled

When calling `WSASend()`, `WSARecv()`, or `WSAIoctl()` on an overlapped socket, either with `lpOverlapped` omitted or with `lpCompletionRoutine` specified, the IO cannot be canceled by the user using `CancelIo` or `CancelIoEx`. `CancelIoEx` returns an error with `GetLastError()` returning `ERROR_NOT_FOUND`. All IOs can be canceled by calling `closesocket()`.

Building an enclave image file

After you have developed an enclave application, you are ready to package it as an enclave image file (.eif). An enclave image file provides the information that is required to launch an enclave. It contains everything that is needed to run the application inside the enclave, including the application code, runtimes, dependencies, operating system, and file system.

This section explains how to create an enclave image file.



First, you need to package the enclave application and its dependencies into a Docker image. A Docker image is a read-only template that provides instructions for creating a Docker container. Nitro Enclaves uses Docker images as a convenient file format for packaging your applications. Docker images are typically used to create Docker containers. However, in this case, you use the Docker image to create an enclave image file instead. For more information about Docker, see the following resources:

- Docker overview
- Orientation and setup
- Build and run your image
- Best practices for writing Docker images

After you have packaged your enclave application into a Docker image, you need to convert the Docker image to an enclave image file. To do this, use the nitro-cli build-enclave AWS Nitro Enclaves CLI command.

> **Important**
>
> The `nitro-cli build-enclave` command is not supported on Windows instances. If you are using a Windows instance, you must complete this step on a temporary Linux instance and then transfer the resulting enclave image file (`.eif`) to your Windows parent instance.
>
> After you have launched the temporary Linux instance and you have installed the AWS Nitro Enclaves CLI, connect to that instance and run the `nitro-cli build-enclave` command. After you have run the command, transfer the enclave image file (`.eif`) to your Windows parent instance where you will create the enclave.

The nitro-cli build-enclave creates an enclave image file and it provides the enclave's measurements. The enclave image file is used to launch the enclave on the parent instance, and the measurements are used to set up the attestation process. For more information, see Cryptographic attestation.

For example, to create an enclave image file from the `hello-world` sample Docker image, use the following command.

```
$ nitro-cli build-enclave --docker-uri hello-world:latest  --output-file hello-
world.eif
```

This command creates an enclave image file named `hello-world.eif`, along with the following output.

```
Start building the Enclave Image...
Enclave Image successfully created.
{
"Measurements": {
    "HashAlgorithm": "Sha384 { ... }",

 "PCR0":"7fb5EXAMPLEcbb68ed99a13d7122abfc0666b926a79d537EXAMPLE445c84217f59cfdd36c08b2c79552928

 "PCR1":"235cEXAMPLEbf6b993c915505f3220e2d82b51aff830ad1EXAMPLEeec1bf0b4ae749d311c663f464cde9f7

 "PCR2":"0f0aEXAMPLE289e872e6ac4d19b0b5ac4a9b020c9829564EXAMPLE610750ce6a86f7edff24e3c0a4a445f2
}
}
```

Creating an enclave

After your enclave applications have been packaged as an enclave image file (`.eif`), you are ready to create the enclave.

> **Important**
>
> You can build enclave images files using the Nitro CLI on any Linux environment, including outside of AWS. To manage the lifecycle of an instance—such as with the `run-enclave` command—you will need to use the Nitro CLI on a parent instance (EC2 instance with Nitro Enclave enabled).

To create the enclave, you need to do the following:

Steps

- Launch the parent instance
- Create the enclave

Launch the parent instance

First, you need to launch the parent instance. The parent instance is the instance from which you allocate the resources for the enclave. You also use this instance to manage the lifecycle of the enclave. For more information about the supported instance types and sizes, see Requirements.

After you launch the parent instance, make a note of the instance ID. You'll need it to generate PCR4, which is needed for attestation. For more information, see Where to get an enclave's measurements.

Console

To launch the parent instance using the Amazon EC2 console

1. Open the Amazon EC2 console at https://console.aws.amazon.com/ec2/.
2. Choose **Launch instance**.
3. (Optional) Under **Name and tags**, for **Name**, enter a descriptive name for your instance.
4. Under **Application and OS Images (Amazon Machine Image)**, choose **Quick Start**, and then choose the operating system (OS) for your instance.
5. Under **Key pair (login)**, for **Key pair name**, choose an existing key pair or create a new one.
6. In the **Summary** panel, choose **Launch instance**.

AWS CLI

To launch a parent instance using the AWS CLI

Use the run-instances command and set the `--enclave-options` parameter to `Enabled=true`.

For example, the following command launches a single `m5.2xlarge` instance using an AMI with an ID of `ami-12345abcde67890a1` and a key pair named `my_key`, and it enables Nitro Enclaves.

```
aws ec2 run-instances \
    --image-id ami-12345abcde67890a1 \
    --count 1 \
    --instance-type m5.2xlarge \
    --key-name my_key \
```

```
    --enclave-options 'Enabled=true'
```

After you launch the parent instance, you must install the AWS Nitro Enclaves CLI and the development tools. If you're using a Linux parent instance, see Install the Nitro Enclaves CLI on Linux. If you're using a Windows parent instance, see Install the Nitro Enclaves CLI on Windows.

Create the enclave

After you have launched the parent instance, you can create the enclave using the enclave image file (`.eif`). When you create the enclave, it boots the enclave application and its dependencies from the enclave image file into the enclave.

> **Note**
>
> You must have the Nitro Enclaves CLI installed on the parent instance in order to create the enclave. For more information, see Nitro Enclaves Command Line Interface.

To create the enclave

On the parent instance, use the nitro-cli run-enclave CLI command and, at a minimum, specify the following:

- The number of vCPUs to allocate to the enclave
- The amount of memory (in MiB) to allocate to the enclave
- An enclave image file

For example, the following command creates an enclave with `4` vCPUs, `1600` MiB of memory, a context ID of `10`, and it uses an enclave image file named `sample.eif`, which is located in the same directory from which the command is being run.

```
nitro-cli run-enclave \
    --cpu-count 2 \
    --memory 1600 \
    --eif-path sample.eif \
    --enclave-cid 10
```

The following is example output.

```
Instance CPUs [1, 3] going offline
Started enclave with enclave-cid: 10, memory: 1600 MiB, cpu-ids: [1, 3]
Sending image to cid: 10 port: 7000
{
"EnclaveID": "i-abc12345def67890a-enc9876abcd543210ef12",
"EnclaveCID": 10,
"NumberOfCPUs": 2,
"CPUIDs": [
    1,
    3
],
"MemoryMiB": 1600
}
```

Getting started with Nitro Enclaves

These tutorials help you get started with AWS Nitro Enclaves. An enclave has no external network connectivity, no persistent storage, and no interactive access. An enclave communicates only with its associated parent instance over a local channel called a *vsock*. Understanding how to launch, validate, and communicate with an enclave helps you design secure, isolated workloads that protect sensitive data.

The following sections walk you through three foundational topics:

- **Hello Enclaves sample application** – Launch an enclave-enabled parent instance, build an enclave image file, validate that the enclave is running, and terminate it when you are finished.
- **Vsock communication** – Establish a virtio-vsock channel between the parent instance and the enclave to pass data securely over the local socket.
- **AWS KMS integration with cryptographic attestation** – Use AWS KMS and cryptographic attestation to decrypt secrets from inside a validated enclave, ensuring that only an enclave launched from a specific enclave image file can access sensitive data.

Topics

- Getting started: Hello Enclaves sample application
- Getting started: Connect the parent instance with an enclave by using virtio-vsock
- Getting started: Connect an enclave with AWS KMS for cryptographic attestation and secrets management

Getting started: Hello Enclaves sample application

The following tutorial walks you through the basics of using AWS Nitro Enclaves. It shows you how to launch an enclave-enabled parent instance, how to build an enclave image file, how to validate that an enclave is running, and how to terminate an enclave when it is no longer needed.

The tutorial uses the *Hello Enclaves* sample application.

> **Important**
>
> The steps for Windows and Linux parent instances are mostly similar. However, the `nitro-cli build-enclave` command referenced in **Step 2: Build the enclave image file** is

not supported on Windows instances. If you are using a Windows instance, you must complete this step on a Linux instance and then transfer the enclave image file (`.eif`) to your Windows parent instance before continuing with the remainder of the tutorial.

Steps

- Step 1: Prepare the enclave-enabled parent instance
- Step 2: Build the enclave image file
- Step 3: Run the enclave
- Step 4: Validate the enclave
- Step 5: Terminate the enclave

Step 1: Prepare the enclave-enabled parent instance

Launch the parent instance that you will use to create the enclave, and prepare the instance to run Nitro Enclaves.

To prepare the parent instance

1. Launch the instance using the run-instances command and set the `--enclave-options` parameter to `true`. At a minimum, you must also specify a Windows or Linux AMI and a supported instance type. For more information, see Requirements.

   The following example command launches an `m5.xlarge` instance using the Amazon Linux 2 Kernel 5.10 AMI.

   ```
   $ aws ec2 run-instances \
   --image-id ami-0b5eea76982371e91 \
   --count 1 \
   --instance-type m5.xlarge \
   --key-name your_key_pair \
   --enclave-options 'Enabled=true'
   ```

2. Connect to the parent instance. For more information about connecting to an instance, see the following topics in the *Amazon EC2 User Guide*.

   - Connect to your Linux instance
   - Connect to your Windows instance

3. Install the AWS Nitro Enclaves CLI on the parent instance.

   - If you are using a Linux parent instance, you must preallocate the memory and vCPUs. For the purposes of this tutorial, you must preallocate at least 2 vCPUs and 512 MiB of memory. For more information, see Install the Nitro Enclaves CLI on Linux.
   - If you are using a Windows parent instance, see Install the Nitro Enclaves CLI on Windows.

Step 2: Build the enclave image file

> **Important**
>
> Only Linux-based operating systems can run inside an enclave. Therefore, you must use a Linux instance to build your enclave image file `.eif`. As a result of this, the `nitro-cli build-enclave` command referenced in this section is not supported on Windows instances. If you are using a Windows parent instance, you must complete this step on a Linux instance and then transfer the resulting enclave image file (`.eif`) to your Windows parent instance.
> In this case, you must launch a temporary Linux instance and install the AWS Nitro Enclaves CLI on that instance. For more information, see Install the Nitro Enclaves CLI on Linux.
> After you have launched the temporary Linux instance and you have installed the AWS Nitro Enclaves CLI, connect to that instance and perform the steps described here. After you have completed the steps, transfer the enclave image file (`.eif`) to your Windows parent instance, reconnect to your Windows parent instance and continue with **Step 3: Run the enclave**.

The Hello Enclave application is located in the `/usr/share/nitro_enclaves/examples/hello` directory.

To build the enclave image file

1. Build a docker image from the application. The following command builds a Docker image named `hello` with a tag of `latest`.

   ```
   $ docker build /usr/share/nitro_enclaves/examples/hello -t hello
   ```

2. Run the following command to verify that the Docker image has been built.

```
$ docker image ls
```

3. Convert the Docker image to an enclave image file by using the nitro-cli build-enclave command. The following command builds an enclave image file named `hello.eif`.

```
$ nitro-cli build-enclave --docker-uri hello:latest --output-file hello.eif
```

Example output

```
Start building the Enclave Image...
Enclave Image successfully created.
"Measurements": {
    "HashAlgorithm": "Sha384 { ... }",
    "PCR0":
 "2bb885ee2104203393c0d2f335f14061a9cd9154e4ede772a6a474d3679348fb33c4917d54fee3f11f9e7a49a
    "PCR1":
 "aca6e62ffbf5f7deccac452d7f8cee1b94048faf62afc16c8ab68c9fed8c38010c73a669f9a36e596032f0b97
    "PCR2":
 "40686da348b450210dcdd234fbb95826ecf81f67e4496b6182ba8eb7ab018977dce07448cd0b7ef44346dc1e2
    }
}
```

The `hello.eif` enclave image file has now been built. Note that the command output includes a set of hashes—PCR0, PCR1, and PCR2. These hashes are measurements of the enclave image and boot up process, and they can be used in the attestation process. The attestation process will not be used in this tutorial.

Step 3: Run the enclave

You can now use the `hello.eif` enclave image file to run the enclave. In this tutorial, you will run an enclave with 2 vCPUs and 512 MiB of memory using the `hello.eif` enclave image file. You will also create the enclave in debug mode.

> **Note**
>
> Enclaves booted in debug mode generate attestation documents with PCRs that are made up entirely of zeros (`000000000000000000000000000000000000000000000000`). These attestation documents cannot be used for cryptographic attestation.

Use the nitro-cli run-enclave command. Specify the vCPUs, memory, and the path to the enclave image file, and include the `--debug-mode` option.

```
$ nitro-cli run-enclave --cpu-count 2 --memory 512 --enclave-cid 16 --eif-path
 hello.eif --debug-mode
```

Example output

```
Start allocating memory...
Started enclave with enclave-cid: 16, memory: 512 MiB, cpu-ids: [1, 3]
{
    "EnclaveID": "i-05f6ed443aEXAMPLE-enc173dfe3eEXAMPLE",
    "ProcessID": 7077,
    "EnclaveCID": 16,
    "NumberOfCPUs": 2,
    "CPUIDs": [
        1,
        3
    ],
    "MemoryMiB": 512
}
```

The enclave is now running. In this sample output, the enclave is created with an ID of `i-05f6ed443aEXAMPLE-enc173dfe3eEXAMPLE`, and an enclave context identifier (EnclaveCID) of 16. The EnclaveCID is like an IP address for the local socket (vsock) between the parent instance and the enclave.

Step 4: Validate the enclave

Now that you have created the enclave, you can use the nitro-cli describe-enclaves command to verify that it is running.

```
$ nitro-cli describe-enclaves
```

```
{
    "EnclaveID": "i-05f6ed443aEXAMPLE-enc173dfe3eEXAMPLE",
    "ProcessID": 7077,
    "EnclaveCID": 16,
    "NumberOfCPUs": 2,
    "CPUIDs": [
        1,
        3
        ],
    "MemoryMiB": 512,
    "State": "RUNNING",
    "Flags": "DEBUG_MODE"
}
```

The command provides information about the enclave, including the enclave ID, number of vCPUs, amount of memory, and its state. In this case, the enclave is in the `RUNNING` state.

Additionally, because you created the enclave in debug mode, you can use the nitro-cli console command to view the read-only console output of the enclave.

```
$ nitro-cli console --enclave-id i-05f6ed443aEXAMPLE-enc173dfe3eEXAMPLE
```

Example output

```
Hello from the enclave side!
Hello from the enclave side!
Hello from the enclave side!
```

In this case, the Hello Enclave application is designed to print `Hello from the enclave side!` to the console every five seconds.

Step 5: Terminate the enclave

If you no longer need the enclave, you can use the `nitro-cli terminate-enclave` command to terminate it.

```
$ nitro-cli terminate-enclave --enclave-id i-05f6ed443aEXAMPLE-enc173dfe3eEXAMPLE
```

Example output

```
Successfully terminated enclave i-05f6ed443aEXAMPLE-enc173dfe3eEXAMPLE.
```

```
{
    "EnclaveID": "i-05f6ed443aEXAMPLE-enc173dfe3eEXAMPLE",
    "Terminated": true
}
```

Getting started: Connect the parent instance with an enclave by using virtio-vsock

The vsock socket is the only communication channel between an Amazon EC2 instance (also called the parent instance) and its associated AWS Nitro Enclaves.

Vsock (VM sockets) is a Linux socket family that enables socket-based communication. A socket address consists of a 32-bit context identifier (CID) and a 32-bit port number. The CID identifies the source or destination, which is either an enclave or the parent instance. By default, the first enclave on a parent instance is assigned CID 16. The parent instance is always reachable at CID 3.

For more information about vsock sockets and packet details, see LINKTYPE_VSOCK on the tcpdump website.

Topics

- Overview: Connect the parent instance with an enclave by using virtio-vsock
- Example: Connect the parent instance and enclave with Python

Overview: Connect the parent instance with an enclave by using virtio-vsock

This pattern shows a simple way to establish a connection between the parent instance and the enclave by using virtio-vsock language bindings, and to pass data over that connection.

With virtio-vsock language bindings, you can create custom, highly restricted, bidirectional communication channels between the parent instance and the enclave. You can initiate connections from the application on the parent instance, or from the application inside the enclave.

Topics

- Communication overview
- Integrate this pattern in your own application

Communication overview

The following diagram shows how the parent instance and enclave communicate over vsock.

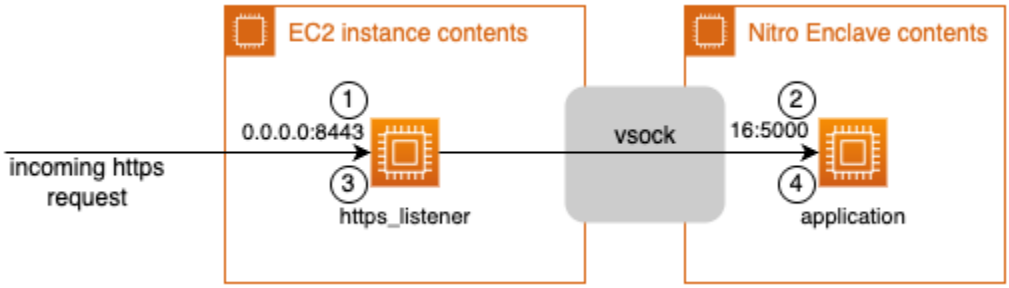


Figure 1: vsock language binding

The preceding diagram depicts a standard scenario where the application on the parent instance dials out to the enclave over vsock and sends data. The enclave accepts the connection, receives the data, processes it, and responds over the open vsock connection.

1. The application on the parent instance starts the enclave.
2. The enclave process starts a vsock listener on CID 16, port `5000`, and waits for incoming connections from the parent instance.
3. The application on the parent instance dials out to the enclave listening on `16:5000` and passes the serialized payload.
4. The enclave application accepts the incoming connection, receives and deserializes the payload, and processes it. It responds to the application on the parent instance over the open vsock connection.
5. The connection closes.

Integrate this pattern in your own application

Keep the following in mind when you use virtio-vsock language bindings to connect the parent and enclave parts of your application:

- Virtio-vsock libraries are available for different programming languages, such as Rust, Go, and Python.
- Consider a non-blocking, multi-threaded implementation inside the enclave to allow parallel processing of requests.

Example: Connect the parent instance and enclave with Python

This example walks you through a setup that connects an application on the parent instance with its enclave by using virtio-vsock language bindings for Python.

The application on the parent instance fetches a fresh set of credentials from the Amazon EC2 Instance Metadata Service Version 2 (IMDSv2), serializes them, and sends them to the enclave over vsock. The enclave receives the credentials and exports them as environment variables so that other processes or SDKs can use them. These credentials are not required for the vsock connection itself. They are necessary if, for example, an AWS SDK must be used inside the enclave to communicate with AWS KMS, as described in Getting started: Connect an enclave with AWS KMS for cryptographic attestation and secrets management.

Topics

- Prerequisites
- Step 1: Prepare and run the enclave
- Step 2: Prepare and run the application on the parent instance
- Step 3: Provide the ciphertext by using curl

Prerequisites

Before you begin, make sure you have the following:

- A virtio-vsock library
- The Nitro CLI. For more information, see Install the Nitro Enclaves CLI on Linux.

Step 1: Prepare and run the enclave

First, set up the enclave. The application inside the enclave opens a vsock listener, accepts incoming connections, and receives data from the application on the parent instance. The enclave application parses the data and exports it as environment variables.

1. Copy the following Python code into a file named `enclave.py`.

```
import socket
import json
import os
import subprocess
```

```
import base64


def export_dict_to_env(data: dict):
    # Export the temporary IMDSv2 session credentials as environment variables.
    # These are short-term credentials from IMDSv2. Do not use long-term access
 keys.
    os.environ['AWS_ACCESS_KEY_ID'] = data['AccessKeyId']
    os.environ['AWS_SECRET_ACCESS_KEY'] = data['SecretAccessKey']
    os.environ['AWS_SESSION_TOKEN'] = data['Token']
    os.environ['CIPHERTEXT'] = data['ciphertext']


def call_subprocess():
    subprocess_args = [
        "/app/per_request.sh"
    ]

    proc = subprocess.Popen(subprocess_args, stdout=subprocess.PIPE)

    # returns b64 encoded plaintext
    result = proc.communicate()[0].decode()

    return result


def parse_cli_result(result: str):
    plaintext_b64 = result.split(":")[1].strip()
    plaintext = base64.standard_b64decode(plaintext_b64).decode()

    return plaintext


if __name__ == "__main__":

    # Create a vsock socket object
    s = socket.socket(socket.AF_VSOCK, socket.SOCK_STREAM)

    # Listen for connection from any CID
    cid = socket.VMADDR_CID_ANY

    # The port should match the client running in parent EC2 instance
    port = 5000
```

```
    # Bind the socket to CID and port
    s.bind((cid, port))

    # Listen for connection from client
    s.listen()

    initial = True

    # run receive and print in while loop to keep main thread alive
    while True:
        c, addr = s.accept()

        payload = c.recv(4096)
        payload_json = json.loads(payload.decode())
        print("payload json: {}".format(payload_json))

        export_dict_to_env(payload_json)
        # Demonstrate subprocess access to environment variables.
        # For production use cases, shell script interactions should be avoided due
 to the security implications.
        subprocess_result = call_subprocess()
        subprocess_result_parsed = parse_cli_result(subprocess_result)
        c.send(str.encode(json.dumps(subprocess_result_parsed)))

        c.close()
```

2. Copy the following into a file named `per_request.sh`. The script reads the `CIPHERTEXT` environment variable, converts it to base64, and writes it to `stdout`.

```
#!/usr/bin/env bash
# Mimic result of kmstool_enclave_cli for later parts
echo "CIPHERTEXT:$(echo $CIPHERTEXT | base64)"
```

3. Copy the following into a file named `Dockerfile`. This file uses a multi-stage build as described on the Docker documentation website. The Dockerfile is used for both the enclave and the parent instance.

```
FROM amazonlinux:2023 AS base

# Install Python 3.12 and pip
RUN dnf install -y python3.12 python3.12-pip openssl && \
    dnf clean all
```

```
# Set python3.12 as default python and pip
RUN ln -sf /usr/bin/python3.12 /usr/bin/python3 && \
    ln -sf /usr/bin/pip3.12 /usr/bin/pip3

WORKDIR /app

FROM base AS enclave
COPY ./enclave.py ./
COPY ./per_request.sh ./

CMD ["python3", "/app/enclave.py"]

FROM base AS parent
RUN pip3 install requests
COPY ./parent.sh ./
COPY ./parent.py ./

CMD ["/app/parent.sh"]
```

4. Add execute permission to `per_request.sh` and build the enclave target of the Dockerfile.

```
chmod +x per_request.sh
docker build --target enclave -t enclave .
```

5. Verify that the Docker image was built successfully.

```
docker images
```

Example output

```
REPOSITORY            TAG             IMAGE ID       CREATED          SIZE
enclave               latest          27f96a96be9d   16 seconds ago   224MB
```

6. Build the enclave image file from the Docker image by using the Nitro CLI.

```
nitro-cli build-enclave --docker-uri enclave:latest --output-file enclave.eif
```

7. Run the enclave, and use the `--debug-mode` flag to enable debug mode.

```
nitro-cli run-enclave --enclave-cid 16 --enclave-name my-enclave --cpu-count 2 --
memory 1600 --eif-path enclave.eif --debug-mode
```

8. Confirm that the enclave is running.

```
nitro-cli describe-enclaves
```

Example output

```
[
  {
    "EnclaveName": "my-enclave",
    "EnclaveID": "i-016e846cc7c56af05-enc196a64a382f7715",
    "ProcessID": 4494,
    "EnclaveCID": 16,
    "NumberOfCPUs": 2,
    "CPUIDs": [
      1,
      3
    ],
    "MemoryMiB": 2048,
    "State": "RUNNING",
    "Flags": "DEBUG_MODE",
    "Measurements": {
      "HashAlgorithm": "Sha384 { ... }",
      "PCR0":
 "26bd4234c3cb6ef9e57d64fd7325ba7a926a3b89ce93981854195a7e397daebe51fcd5002b8af202a5e0ba6f1
      "PCR1":
 "0343b056cd8485ca7890ddd833476d78460aed2aa161548e4e26bedf321726696257d623e8805f3f605946b3d
      "PCR2":
 "a7369cee5c5c945fdbf7a1c71e99c45417379804ed5f50433c587023c815cfbe65f8ff3986038ff77f44b08ee
    }
  }
]
```

9. Because the enclave is running in debug mode, you can attach to its console to view the enclave's console output, such as the `print` statement in `enclave.py`.

```
nitro-cli console --enclave-name my-enclave
```

Step 2: Prepare and run the application on the parent instance

The application on the parent instance initiates a connection to a specific enclave, identified by its unique CID and port. It then fetches fresh credentials from IMDSv2 and transmits them to the enclave, along with a ciphertext field, in serialized JSON format.

1. Validate that the enclave is running by using the `nitro-cli describe-enclaves` command, and verify that the enclave is assigned CID 16 (the default for the first enclave). The output is similar to the following.

```
[
  {
    "EnclaveName": "my-enclave",
    "EnclaveID": "i-016e846cc7c56af05-enc196aaa3fb3bf6f4",
    "ProcessID": 14717,
    "EnclaveCID": 16,
    "NumberOfCPUs": 2,
    "CPUIDs": [
      1,
      3
    ],
    "MemoryMiB": 2048,
    "State": "RUNNING",
    "Flags": "DEBUG_MODE",
    "Measurements": {
      "HashAlgorithm": "Sha384 { ... }",
      "PCR0":
 "b078785234059e040259dd555d900804124056877295 0f08602812b301e4b2b94c0ca68c5021856443 7d6d43b
      "PCR1":
 "0343b056cd8485ca7890ddd833476d78460aed2aa161548e4e26bedf321726696257d623e8805f3f605946b3d
      "PCR2":
 "4366c961ee795e2c85523ca4949778d4ea1659676890939347651c37f062a3e560b44fcc2eca5edbc1593f513
    }
  }
]
```

2. Copy the following code into a file named `parent.py`. This code creates a simple HTTPS listener inside the Docker container. When a POST request arrives, the listener fetches a fresh set of credentials from IMDSv2, merges them with the passed payload, and sends the result into the enclave.

```
import requests
```

```
import json
import socket
import argparse
from http.server import HTTPServer, BaseHTTPRequestHandler
import ssl


class HelloHandler(BaseHTTPRequestHandler):

    def _get_aws_credentials_from_imdsv2(self):
        """Get AWS credentials from IMDSv2 and return as JSON."""
        # Get IMDSv2 token
        token_headers = {'X-aws-ec2-metadata-token-ttl-seconds': '21600'}
        token_url = 'http://169.254.169.254/latest/api/token'
        token = requests.put(token_url, headers=token_headers).text

        # Set headers for subsequent requests
        headers = {'X-aws-ec2-metadata-token': token}

        # Get IAM role name
        role_url = 'http://169.254.169.254/latest/meta-data/iam/security-
credentials/'
        role_name = requests.get(role_url, headers=headers).text

        # Get credentials
        creds_url = f'http://169.254.169.254/latest/meta-data/iam/security-
credentials/{role_name}'
        credentials = requests.get(creds_url, headers=headers).json()

        # Return formatted credentials
        return {
            'AccessKeyId': credentials['AccessKeyId'],
            'SecretAccessKey': credentials['SecretAccessKey'],
            'Token': credentials['Token'],
            'Expiration': credentials['Expiration']
        }

    def _call_enclave(self, cid, port, payload):

        # Create a vsock socket object
        s = socket.socket(socket.AF_VSOCK, socket.SOCK_STREAM)

        # Connect to the enclave
        s.connect((cid, port))
```

```
        # Get fresh AWS credentials from EC2 metadata service
        payload = {**self._get_aws_credentials_from_imdsv2(),
                   'ciphertext': payload['ciphertext']}

        # Send payload to enclave
        s.send(str.encode(json.dumps(payload)))

        # receive data from the server
        payload_processed = s.recv(1024).decode()

        # close the connection
        s.close()
        return payload_processed

    def _set_response(self, http_status=200):
        self.send_response(http_status)
        self.send_header("Content-type", "application/json")
        self.end_headers()

    def do_POST(self):
        content_length = int(self.headers["Content-Length"])
        post_data = self.rfile.read(content_length)
        payload = json.loads(post_data.decode("utf-8"))

        enclave_result = self._call_enclave(16, 5000, payload)
        response = {'enclaveResult': enclave_result}

        self._set_response()
        self.wfile.write(json.dumps(response).encode("utf-8"))


if __name__ == "__main__":
    parser = argparse.ArgumentParser(description="Minimal HTTPS server")
    parser.add_argument('--port', type=int, default=8443, help='Port to listen on')
    args = parser.parse_args()

    httpd = HTTPServer(('0.0.0.0', args.port), HelloHandler)
    print(f"Serving on https://0.0.0.0:{args.port}")
    context = ssl.SSLContext(ssl.PROTOCOL_TLS_SERVER)
    context.load_cert_chain(certfile="cert.pem", keyfile="key.pem")
    httpd.socket = context.wrap_socket(httpd.socket, server_side=True)
    httpd.serve_forever()
```

3. Copy the following into a file named `parent.sh`. The script creates a self-signed certificate by using `openssl` and starts the HTTPS server defined in `parent.py`.

```
#!/usr/bin/env bash

# Create self signed cert via openssl and start simple https server listening on
 8443
openssl req -nodes -new -x509 -keyout key.pem -out cert.pem -days 1 \
   -subj "/C=US/ST=State/L=City/O=Company/OU=Org/CN=enclave"

# Start https server in foreground to keep main thread alive
python3 parent.py --port 8443
```

4. Add execute permissions to `parent.sh` and build the Docker image by using the parent target.

```
chmod +x parent.sh
docker build --target parent -t parent .
```

5. Start the Docker container on the parent instance with the required `seccomp` permissions.

```
docker run -d --rm --security-opt seccomp=unconfined --name parent -p 8443:8443
 parent:latest
```

6. Inspect the Docker logs on the parent instance.

```
docker logs -f parent
```

Step 3: Provide the ciphertext by using curl

Use `curl` to post your ciphertext to the local HTTPS endpoint on port 8443.

```
curl -k --header "Content-Type: application/json" \
  --request POST \
  --data '{"ciphertext":"MySecretCipherText"}' \
  https://localhost:8443 | jq '.'
```

The output is similar to the following.

```
{
```

```
  "enclaveResult": "\"MySecretCipherText\\n\""
}
```

The HTTPS server on the parent instance parsed the request from `curl` and sent the payload to the enclave. The enclave processed it and returned the result over vsock as the response to the `POST` request.

Getting started: Connect an enclave with AWS KMS for cryptographic attestation and secrets management

Use this pattern to access secrets only from inside a validated enclave.

You build an enclave from an enclave image file (EIF) that you generate from a Docker image. The EIF contains unencrypted copies of all code and data, so unencrypted secrets must not be part of the EIF. To make secret data accessible only from inside an enclave, use AWS KMS. AWS KMS can grant permission for decrypt operations exclusively to enclaves launched from a particular EIF. For more information, see Using cryptographic attestation with AWS KMS and Cryptographic attestation.

To authenticate the enclave to AWS KMS, provide an attestation document as part of your AWS KMS operation request. This attestation document contains cryptographic hashes (PCR values) of the enclave state, including PCR0, which is a hash over the entire EIF. AWS root of trust signs the document. This signature gives AWS KMS assurance that the request originates from an AWS Nitro confidential compute environment.

An enclave does not have network access. It communicates only with its parent instance over vsock. To access AWS KMS from within the enclave, use the `vsock-proxy` and `kmstool-enclave-cli` tools provided by AWS.

Topics

- Communication overview
- Integrate this pattern in your own application
- Example: Decrypt a secret with AWS tooling

Communication overview

The following diagram shows how an enclave uses AWS KMS and cryptographic attestation to decrypt a secret.

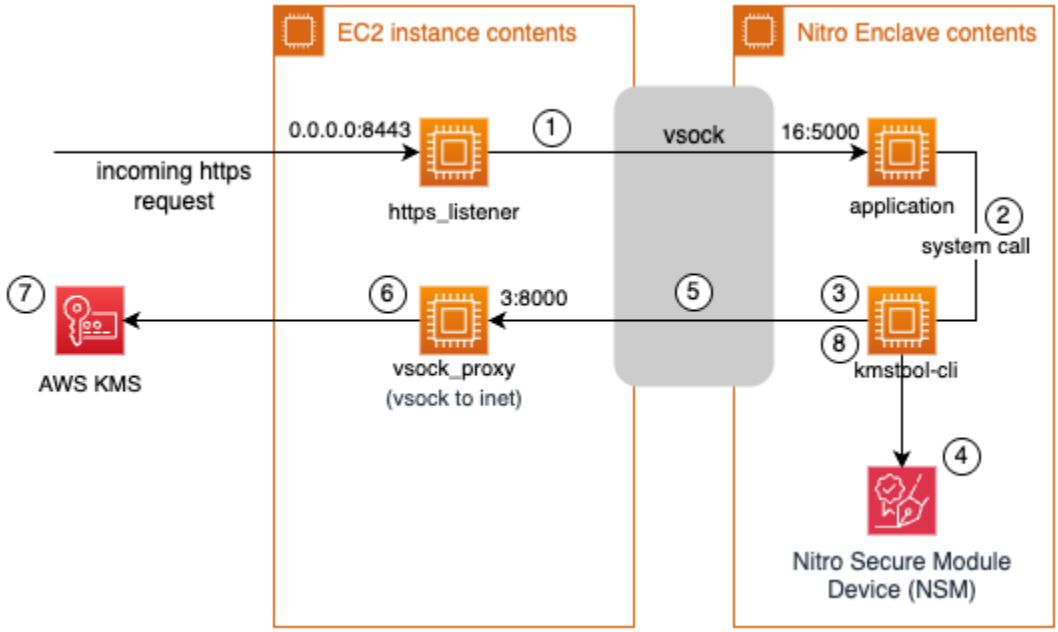


Figure 2: Decrypt with AWS KMS and cryptographic attestation

The preceding diagram shows how your application interacts with AWS KMS through a prepackaged CLI tool named `kmstool-enclave-cli`.

1. The parent instance passes credentials and ciphertext into the enclave over virtio-vsock. For more information, see Getting started: Using the virtio-vsock.
2. Your application invokes the `kmstool-enclave-cli` binary through a system call.
3. The CLI utility generates an ephemeral private/public key pair.
4. The CLI utility requests an attestation document from the Nitro Secure Module (NSM) device and includes the public key.
5. The CLI creates a AWS KMS decrypt request by using a standard AWS SDK and attaches the attestation document from the previous step. The SDK dials out to an HTTPS AWS KMS endpoint over vsock.
6. The `vsock-proxy` process on the parent instance listens on CID `3`, port `8000`. It accepts the connection and transparently forwards the packets to the configured AWS KMS endpoint. A

secure, bidirectional TLS connection is established between the AWS KMS endpoint and the enclave.

7. AWS KMS receives the decrypt request, validates the attestation document, and decrypts the payload. If the attestation document contains a public key, AWS KMS uses this key to re-encrypt the plaintext so that only the owner of the matching private key can read the sensitive information.
8. The CLI receives the AWS KMS response and decrypts the payload with the ephemeral private key from step 3.
9. The connection closes.

Integrate this pattern in your own application

Inside the enclave

Inside the enclave, complete the following steps.

1. Receive AWS credentials from the parent instance. You need these credentials to authenticate to AWS KMS. Pass them as part of your own data channel. For more information, see Getting started: Using the virtio-vsock.
2. Generate a local ephemeral private/public key pair for plaintext encryption of decrypt responses.
3. Obtain an attestation document from the Nitro Secure Module (NSM) device and include the ephemeral public key.
4. All AWS SDKs natively support attestation documents through the `Recipient` field. For more information, see Decrypt in the *AWS Key Management Service Developer Guide*.

Inside the parent instance

Inside the parent instance, complete the following steps.

1. Provide a mechanism to get fresh AWS credentials from IMDSv2 and pass them into the enclave with the ciphertext.
2. Use the default `vsock-proxy` service provided by AWS to connect to AWS KMS. Add the specific AWS KMS endpoint to the allow list.

Example: Decrypt a secret with AWS tooling

The following example walks you through setting up a vsock-based communication channel between the enclave and the parent instance, and decrypting a secret from inside the enclave by using a CLI tool provided by AWS named `kmstool-enclave-cli`.

> **Note**
>
> Use the same Region consistently throughout this example. The Region that you specify when you encrypt the secret (Step 1), the AWS KMS endpoints in the `vsock-proxy` allow list (Step 2), and the Region that you pass to `kmstool-enclave-cli` (Step 3) must all match. This example uses `us-east-1`.

Topics

- Prerequisites
- Step 1: Create a AWS KMS key and encrypt a secret
- Step 2: Prepare the parent instance
- Step 3: Run inside the enclave
- Step 4: Provide the ciphertext by using curl

Prerequisites

> **Important**
>
> This example builds on the Getting started: Using the virtio-vsock example, and it reuses the scripts created in that example. Complete that example before you begin.

Ensure that you have the following before you begin.

- The `vsock-proxy` systemd service on the parent instance, which is required to communicate with the AWS KMS endpoint.
- The kmstool-enclave-cli binary on GitHub, or a similar binary, inside the enclave.

Step 1: Create a AWS KMS key and encrypt a secret

1. Create a symmetric AWS KMS key by following the steps in Creating symmetric encryption AWS KMS keys in the *AWS Key Management Service Developer Guide*. Note the key ID. Use the following command templates to encode your secret and pass it to AWS KMS for encryption. Replace the key ID placeholder with your key ID.

```
ciphertext=$( echo "Hello World" | base64 )
aws kms encrypt --key-id "<alias/your-key-alias-or-key-id>" --plaintext
 ${ciphertext} --output text --query CiphertextBlob --region us-east-1
```

2. Run the `nitro-cli describe-enclaves` command to get the PCR0 value for the AWS KMS key resource policy.

   If you started the enclave in debug mode, use the following value for PCR0.

```
000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
```

   Otherwise, use the PCR0 value from the output of the `nitro-cli describe-enclaves` command, for example:

```
b078785234059e040259dd555d900804124056877295 0f08602812b301e4b2b94c0ca68c50218564437d6d43b38
```

3. Update the following AWS KMS key policy template with the correct Amazon EC2 role ARN and `kms:RecipientAttestation:PCR0` value, and then follow the steps in Key policies in AWS KMS in the *AWS Key Management Service Developer Guide* to set the policy.

```
{
  "Sid" : "Enable enclave data processing",
  "Effect" : "Allow",
  "Principal" : {
    "AWS" : "<arn:aws:iam::111122223333:role/data-processing>"
  },
  "Action": [
    "kms:Decrypt"
  ],
  "Resource" : "*",
  "Condition": {
    "StringEqualsIgnoreCase": {
      "kms:RecipientAttestation:PCR0": "<EIF image sha384>"
    }
```

```
  }
}
```

Step 2: Prepare the parent instance

Use the `vsock-proxy` systemd service provided by AWS as a vsock-to-TCP outbound proxy. This proxy allows the enclave to dial out to AWS KMS. Before you start the systemd service on the parent instance, add the specific AWS KMS endpoints, including the Region, to the `vsock-proxy.yaml` allow list, as shown in the following example.

```
VSOCK_PROXY_YAML=/etc/nitro_enclaves/vsock-proxy.yaml
cat <<'EOF' > $VSOCK_PROXY_YAML
allowlist:
- {address: kms.us-east-1.amazonaws.com, port: 443}
- {address: kms-fips.us-east-1.amazonaws.com, port: 443}
EOF

systemctl enable --now nitro-enclaves-vsock-proxy.service
```

Step 3: Run inside the enclave

1. Create a Dockerfile that includes the `kmstool_enclave_cli` binary and the libraries provided by AWS. For more information, see the kmstool-enclave-cli documentation on GitHub.

   The CLI requires parameters such as the Region, AWS credentials, and the ciphertext. Transfer these into the enclave and export them as environment variables. For more information, see Step 1: Prepare and run the enclave. By default, you don't need to specify the AWS KMS key ID because it is encoded in the ciphertext.

2. Update the `per_request.sh` file from Step 1: Prepare and run the enclave to invoke the `kmstool_enclave_cli` binary and return the standard output as the result.

   ```
   REGION=us-east-1
   /app/kmstool_enclave_cli decrypt \
     --region ${REGION} \
     --proxy-port 8000 \
     --aws-access-key-id ${AWS_ACCESS_KEY_ID} \
     --aws-secret-access-key ${AWS_SECRET_ACCESS_KEY} \
     --aws-session-token ${AWS_SESSION_TOKEN} \
   ```

```
  --ciphertext ${CIPHERTEXT}
```

3. Rebuild the enclave Dockerfile, convert the container to an enclave image file, and run the enclave as described in Step 1: Prepare and run the enclave.

Step 4: Provide the ciphertext by using curl

Use `curl` to post your ciphertext to the local HTTPS endpoint.

```
curl -k --header "Content-Type: application/json" \
  --request POST \
  --data '{"ciphertext":"MySecretCipherText"}' \
  https://localhost:8443 | jq '.'
```

The output is similar to the following.

```
{
  "enclaveResult": "\"Hello World\\n\""
}
```

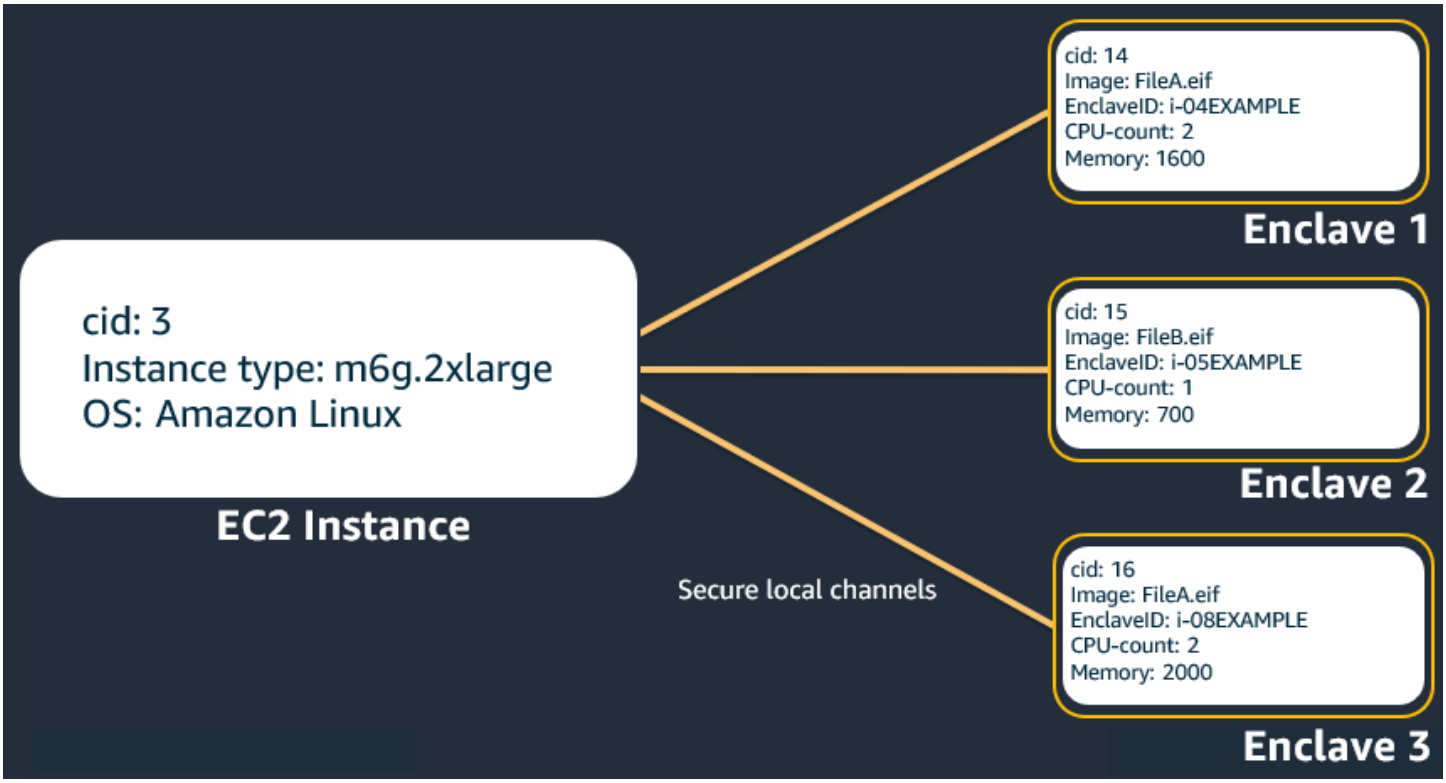
The HTTPS server on the parent instance parsed the `curl` request. It augmented the payload with fresh AWS credentials from IMDSv2 and sent it into the enclave. Inside the enclave, the payload was passed to `kmstool-enclave-cli` through environment variables. `kmstool-enclave-cli` created an attestation document and dialed out to AWS KMS through the `vsock-proxy` that you configured. AWS KMS validated the attestation document and decrypted the payload. The decrypted result was returned to the enclave and used as the response to your POST request.

Working with multiple enclaves

You can create up to four separate enclaves from a single Amazon EC2 parent instance. Consider the following before using multiple enclaves.

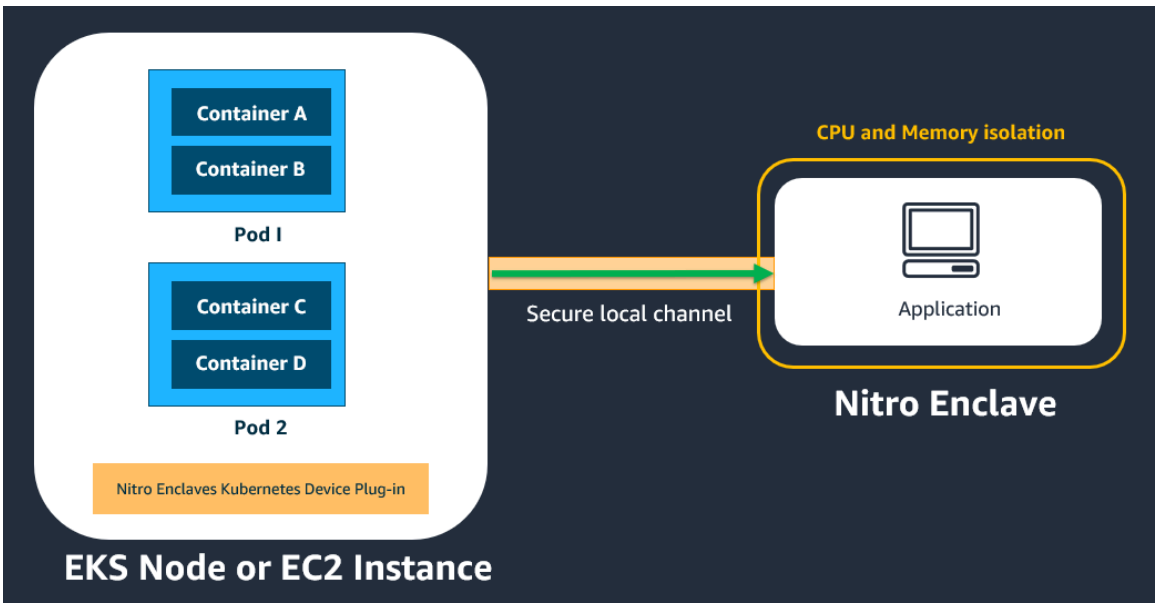
- When launching a parent instance, choose an instance type that has enough vCPUs and memory for both the parent instance and the additional enclaves. If multi-threading is enabled, you must leave at least 2 vCPUs for the parent instance. If multi-threading is not enabled, you must leave at least 1 vCPU for the parent instance. For example, if multi-threading is enabled and you intend to run 4 enclaves with 4 vCPUs each, you must select an instance type that has at least 18 vCPUs (2 for the parent instance and 16 for the enclaves).
- When you install the Nitro CLI, you must configure the allocator service to preallocate enough vCPUs and memory for all of the enclaves. For example, if you intend to run 3 enclaves with 4 vCPUs and 2 GiB memory each, you must preallocate 12 vCPUs and 6 GiB of memory. For more information, see the section called “Install the CLI on Linux”.
- Each enclave communicates with the parent instance over vsock. Each enclave has its own vsock address that is defined by a context identifier (CID). There is no vsock connection between the enclaves.
- Each enclave has its own unique ID.
- Each enclave can be individually terminated by specifying its enclave ID.
- Each enclave can be configured with a different number of vCPUs or amount of memory.
- Each enclave on a parent instance can be created from the same or a different enclave image file.

The following image illustrates an example of using multiple enclaves. In this example, there is a single parent instance with 3 running enclaves. The parent instance is a `m6g.2xlarge`, which has 8 vCPUs and 32 GiB memory, running Amazon Linux 2. The parent instance has a CID of 3, and enclaves 1, 2, and 3 have unique CIDs of 14, 15, 16 respectively. Each enclave has a unique enclave ID; each ID is prefixed with the parent instance ID. Enclaves 1 and 3 were launched with the same enclave image file (`FileA.eif`), while enclave 2 was launched with a different enclave image file (`FileB.eif`). Enclave 1 has been launched with 2 vCPUs and 1600 MiB memory, enclave 2 with 1 vCPU and 700 MiB memory, and enclave 3 with 2 vCPUs and 2000 MiB memory. In total, the enclaves have been allocated with 5 vCPUs and 4300 MiB (4.2 GiB) of memory, which leaves the parent instance with 3 vCPUs and 27.8 GiB of memory. Each enclave has a vsock channel to communicate with the parent instance.


cid: 3
Instance type: m6g.2xlarge
OS: Amazon Linux
EC2 Instance
Secure local channels
cid: 14
Image: FileA.eif
EnclaveID: i-04EXAMPLE
CPU-count: 2
Memory: 1600
Enclave 1
cid: 15
Image: FileB.eif
EnclaveID: i-05EXAMPLE
CPU-count: 1
Memory: 700
Enclave 2
cid: 16
Image: FileA.eif
EnclaveID: i-08EXAMPLE
CPU-count: 2
Memory: 2000
Enclave 3

Using Nitro Enclaves with Amazon EKS

You can use Amazon Elastic Kubernetes Service to orchestrate, scale, and deploy Nitro Enclaves from a Kubernetes pod. Kubernetes is an open source platform for container orchestration. The following diagram provides a conceptual overview of how Nitro Enclaves integrates with Amazon EKS.



> **Important**
>
> All pods and containers in the same Amazon EKS node or Amazon EC2 instance that has the Nitro Enclaves Kubernetes device plugin installed will be able to communicate with the enclave that is attached to that parent Amazon EC2 instance.

For more information about Amazon EKS see the Amazon Elastic Kubernetes Service User Guide.

This tutorial shows how to create an Amazon EKS cluster with a managed node group and one enclave-enabled node. It shows how to install the Nitro Enclaves Kubernetes device plugin, how to prepare the Hello Enclaves sample application for deployment, and how to deploy the prepared Hello Enclaves Docker image to the cluster.

There are two key components to this process:

- Launch templates. The process requires a launch template that is properly configured. The launch template must have enclaves enabled and an it must include specific user data that is

provided in Step 1: Create a launch template. This launch template will be used to create the enclave-enabled nodes in the cluster.

- The Nitro Enclaves Kubernetes device plugin. This device plugin gives your pods and containers the ability to create and terminate enclaves using the Nitro Enclaves Command Line Interface. The device plugin works with both Amazon EKS and self-managed Kubernetes nodes.

> **Tip**
>
> To simplify the build process, we also provide an open source tool called **enclavectl** that you can use to build and deploy your enclave applications to an Amazon EKS cluster. Using **enclavectl**, you can create an enclave-enabled Amazon EKS cluster and install the Nitro Enclaves device plugin as a daemonset. We also provide some sample applications and a tutorial to demonstrate how to build and run your own enclave applications in an Amazon EKS cluster. For more information about **enclavectl**, see the Nitro Enclaves with Kubernetes GitHub repo.

Topics

- Prerequisites
- Step 1: Create a launch template
- Step 2: Create Kubernetes cluster and node
- Step 3: Install the Nitro Enclaves Kubernetes device plugin
- Step 4: Prepare the image
- Step 5: Deploy the application to the cluster

Prerequisites

- This tutorial assumes familiarity with Kubernetes concepts. For more information, see the Kubernetes documentation.
- The following tools are required to complete this tutorial:
  - bash shell
  - **AWS CLI** version 2. For more information about installing the AWS CLI, see Getting started with the AWS CLI.

- **eksctl**, a simple command line tool for creating and managing Kubernetes clusters on Amazon EKS. For more information, see Installing or updating eksctl.
- **Docker**, an open platform used for packaging your enclave applications into images that can be deployed into containers on your worker nodes. For more information, see Get Docker.
- **jq**, a command line JSON processor. For more information, see Download jq.
- **kubectl** version 1.20 and later versions that include the Docker runtime. kubectl is the Kubernetes command line tool that enables you to deploy applications, inspect and manage cluster resources, and view logs. For more information, see Installing or updating kubectl in the *Amazon EKS User Guide*.

Step 1: Create a launch template

Create a launch template that will be used to launch the enclave-enabled worker nodes (Amazon EC2 instances) in the cluster. You can create the launch template using either the `create-launch-template` AWS CLI command or the Amazon EC2 console.

When you create the launch template, you must do the following:

1. Specify a supported instance type.
2. Enable Nitro Enclaves.
3. Specify the following user data, which automates the AWS Nitro Enclaves CLI installation, and preallocates the memory and the vCPUs for enclaves on the instance.

   The `CPU_COUNT` and `MEMORY_MIB` variables in the user data specify the number of vCPUs and amount of memory (in MiB) respectively. For the purpose of this tutorial, the user data below specifies 2 vCPUs and 768 MiB of memory.

   > **Note**
   >
   > You can specify a custom number of vCPUs and amount of memory, depending on your workload and instance type. When you create an enclave on the worker node, the requested memory and vCPUs can't exceed the values that you specified here.
   > You can also include any other instructions in the user data that are required for your application.

Amazon Linux 2023

```
MIME-Version: 1.0
Content-Type: multipart/mixed; boundary="==MYBOUNDARY=="

--==MYBOUNDARY==
Content-Type: text/cloud-config; charset="us-ascii"
MIME-Version: 1.0
Content-Transfer-Encoding: 7bit
Content-Disposition: attachment; filename="cloud-config.txt"

#cloud-config
bootcmd:
 - dnf install aws-nitro-enclaves-cli -y

--==MYBOUNDARY==
Content-Type: text/x-shellscript; charset="us-ascii"

#!/bin/bash -e
readonly NE_ALLOCATOR_SPEC_PATH="/etc/nitro_enclaves/allocator.yaml"
# Node resources that will be allocated for Nitro Enclaves
readonly CPU_COUNT=$CONFIG_NODE_ENCLAVE_CPU_LIMIT
readonly MEMORY_MIB=$CONFIG_NODE_ENCLAVE_MEMORY_LIMIT_MIB

# Update enclave's allocator specification: allocator.yaml
sed -i "s/cpu_count:.*/cpu_count: \$CPU_COUNT/g" \$NE_ALLOCATOR_SPEC_PATH
sed -i "s/memory_mib:.*/memory_mib: \$MEMORY_MIB/g" \$NE_ALLOCATOR_SPEC_PATH
# Restart the nitro-enclaves-allocator service to take changes effect.
systemctl enable --now nitro-enclaves-allocator.service
echo "NE user data script has finished successfully."
--==MYBOUNDARY==--
```

Amazon Linux 2

```
MIME-Version: 1.0
Content-Type: multipart/mixed; boundary="==MYBOUNDARY==

--==MYBOUNDARY==
Content-Type: text/x-shellscript; charset="us-ascii"

#!/bin/bash -e
```

```
readonly NE_ALLOCATOR_SPEC_PATH="/etc/nitro_enclaves/allocator.yaml"
# Node resources that will be allocated for Nitro Enclaves
readonly CPU_COUNT=2
readonly MEMORY_MIB=768

# This step below is needed to install nitro-enclaves-allocator service.
amazon-linux-extras install aws-nitro-enclaves-cli -y

# Update enclave's allocator specification: allocator.yaml
sed -i "s/cpu_count:.*/cpu_count: $CPU_COUNT/g" $NE_ALLOCATOR_SPEC_PATH
sed -i "s/memory_mib:.*/memory_mib: $MEMORY_MIB/g" $NE_ALLOCATOR_SPEC_PATH
# Restart the nitro-enclaves-allocator service to take changes effect.
systemctl restart nitro-enclaves-allocator.service
echo "NE user data script has finished successfully."
--==MYBOUNDARY==--
```

> **Note**
>
> If you create the launch template using the AWS CLI, you must provide the user data as base64-encoded text.

4. Note the launch template ID (for example, `lt-01234567890abcdef`; you'll need it in the following step.

For more information about creating a launch template, see Create a launch template in the *Amazon EC2 User Guide*.

Step 2: Create Kubernetes cluster and node

Create the cluster with node groups and worker nodes. In this tutorial, we use the **eksctl** command line tool to create an Amazon EKS cluster with one managed node group with one worker node using the launch template created in the previous step.

To create the cluster, node group, and worker node

1. Create a cluster configuration file named `cluster_config.yaml` and add the following configuration, which specifies the following:

   - The name of the cluster (`metadata:name`)

- The AWS Region in which to create the cluster (`region`)
- The name of the node group (`managedNodeGroups:name`)
- The ID and version of the launch template to use to create the worker nodes (`id` and `version`)
- The number of nodes in the node group (`desiredCapacity`)

For the purpose of this tutorial, the configuration file creates a cluster named `ne-cluster` in `us-east-1`, it creates 1 node in a node group named `ne-group` using version 1 of launch template `lt-01234567890abcdef`.

```
apiVersion: eksctl.io/v1alpha5
kind: ClusterConfig

metadata:
  name: ne-cluster
  region: us-east-1
  version: "1.30"

managedNodeGroups:
  - name: ne-group
    launchTemplate:
      id: lt-01234567890abcdef
      version: "1"
    desiredCapacity: 1
```

For more information about cluster configuration files, see Using Config Files in the *eksctl documentation*.

2. Create the cluster, node group, and worker node using the cluster configuration file. Run the following **eksctl** command and specify the cluster configuration file created in the previous step.

```
$ eksctl create cluster -f cluster_config.yaml
```

After the cluster is created, you will see output similar to the following.

```
...
[#]  EKS cluster "ne-cluster" in us-east-1 region is ready
```

> **Note**
>
> When you create an Amazon EKS cluster using **eksctl**, the tool automatically preconfigures **kubectl** so that it can find and access the Amazon EKS cluster. If you create a self-managed cluster using other tooling, you might need to manually configure **kubectl** so that it can communicate with your cluster. To check the **kubectl** configuration, run `kubectl cluster-info`. If you see a URL response, **kubectl** is correctly configured to access your cluster. For more information, see Organizing Cluster Access Using kubeconfig Files in the *Kubernetes documentation*.

Step 3: Install the Nitro Enclaves Kubernetes device plugin

Deploy the Nitro Enclaves Kubernetes device plugin to the cluster and then enable it on each worker node in the cluster using **kubectl**. The plugin enables the pods on each worker node to access the Nitro Enclaves device driver. The plugin is deployed to the Kubernetes cluster as a daemonset.

To deploy and enable the Nitro Enclaves Kubernetes device plugin

1. Deploy the Nitro Enclaves Kubernetes device plugin to the cluster using the following command.

   ```
   $ kubectl apply -f https://raw.githubusercontent.com/aws/aws-nitro-enclaves-k8s-device-plugin/main/aws-nitro-enclaves-k8s-ds.yaml
   ```

   To customize the Nitro Enclaves Kubernetes device plugin before deployment (for example, turning on the `ENCLAVE_CPU_ADVERTISEMENT` feature, download and edit the manifest before deployment.

   Download

   ```
   curl -O https://raw.githubusercontent.com/aws/aws-nitro-enclaves-k8s-device-plugin/main/aws-nitro-enclaves-k8s-ds.yaml
   ```

   Edit

You can use any editor to manipulate the `aws-nitro-enclaves-k8s-ds.yaml` file or a command line tool, such as `yq`. See the following example.

```
yq ea '
  select(.kind == "DaemonSet")
    |= (
      .spec.template.spec.containers[]
        |= (
          select(.name == "aws-nitro-enclaves-k8s-dp").env[]
            |= (
              select(.name == "ENCLAVE_CPU_ADVERTISEMENT").value = "true"
            )
        )
    )
  // .
' -i aws-nitro-enclaves-k8s-ds.yaml
```

Deployment

```
kubectl apply -f aws-nitro-enclaves-k8s-ds.yaml
```

2. Get the name of the worker node on which to install the Nitro Enclaves Kubernetes device plugin using the following command.

```
$ kubectl get nodes
```

The following is example output.

```
NAME                                          STATUS   ROLES   AGE   VERSION
ip-123-123-123-123.us-east-1.compute.internal   Ready    <none> 21h   v1.30.15-eks-
fb459a0
```

3. Enable the Nitro Enclaves Kubernetes device plugin on the worker node. Use the following **kubectl** command and specify the node name from the previous step.

```
$ kubectl label node node_name aws-nitro-enclaves-k8s-dp=enabled
```

For example:

```
$ kubectl label node ip-123-123-123-123.us-east-1.compute.internal aws-nitro-
enclaves-k8s-dp=enabled
```

Step 4: Prepare the image

Nitro Enclaves uses Docker images as a convenient file format for packaging your applications. You must build the Docker image that includes your enclave application and any other commands that are needed to run the application. This Docker image will be deployed to the worker node in the following step.

AWS provides a command line tool, **enclavectl** that automates the steps that are needed to build an enclave image file and to package your enclave image file into a Docker image. Additionally, the tool includes features that automate Amazon EKS cluster and node group creation, and application deployment. For an end-to-end tutorial on how to use the **enclavectl** tool to automate cluster creation, application packaging, and application deployment, see the aws-nitro-enclaves-with-k8s readme file.

> **Note**
>
> You can also perform these steps manually using Docker and the Nitro CLI. For more information, see Building an enclave image file.

In this tutorial, we use the **enclavectl** tool to package the *Hello Enclaves* sample application into a Docker image.

To prepare the image

1. The **enclavectl** utility can be found in the `aws-nitro-enclaves-with-k8s` GitHub repo. Clone the GitHub repo and navigate into the directory.

   ```
   $ git clone git@github.com:aws/aws-nitro-enclaves-with-k8s.git && cd aws-nitro-
   enclaves-with-k8s
   ```

2. Source the `env.sh` script to add the **enclavectl** tool to you PATH variable.

   ```
   $ source env.sh
   ```

3. Configure the **enclavectl** for the tutorial. The `settings.json` file includes some default parameters that are used only if you create a cluster using **enclavectl**. Since the cluster was created manually in the previous steps, the parameters in the `settings.json` are not used; but you must run this command to configure the tool before using it.

```
$ enclavectl configure --file settings.json
```

4. Build the Hello Enclaves enclave image file and package it into a Docker image. The required files are located in the `/container/hello` directory. Use the `enclavectl build` command and specify the name of the directory.

```
$ enclavectl build --image hello
```

> **Tip**
>
> You can also use the **enclavectl** tool to package your own enclave applications into a Docker image. To do this, you must create a new directory with the name of your application in the `/container` directory. For example, `/aws-nitro-enclaves-with-k8s/container/`*`my-app`*. Then, you must create your Dockerfile and an `enclave_manifest.json` file in this directory. Then, when you run the `enclavectl build` command, for `--image` specify the name of the directory that you created. For example, `enclavectl build --image my-app`.
> For more information about how to use the **enclavectl** tool to package you applications, see How to create your own application

5. The Docker image is created with a name in the following format: `hello-`*`unique_uuid`*. To view the full name of the image, run the following command.

```
$ docker image ls | grep hello
```

Step 5: Deploy the application to the cluster

Finally, you need to deploy the application to your cluster.

To deploy the application to the cluster

1. Create a deployment specification. Create a new file named `deployment_spec.yaml` and add the following content.

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: unique_deployment_name
spec:
  replicas: 1
  selector:
    matchLabels:
      app: application_name
  template:
    metadata:
      labels:
        app: application_name
    spec:
      containers:
      - name: unique container_name
        image: docker_image_name:image_tag
        command: ["docker_image_entry_point"]
        resources:
          limits:
            aws.ec2.nitro/nitro_enclaves: "1"
            hugepages-2Mi: 768Mi
            cpu: 250m
          requests:
            aws.ec2.nitro/nitro_enclaves: "1"
            hugepages-2Mi: 768Mi
        volumeMounts:
        - mountPath: /dev/hugepages
          name: hugepage
          readOnly: false
      volumes:
      - name: hugepage-2mi
        emptyDir:
          medium: HugePages-2Mi
      - name: hugepage-1gi
        emptyDir:
          medium: HugePages-1Gi
      tolerations:
```

```
      - effect: NoSchedule
        operator: Exists
      - effect: NoExecute
        operator: Exists
```

The deployment specification must include the following Nitro Enclaves specific sections:

- ```
  limits:
    aws.ec2.nitro/nitro_enclaves: "1"
    hugepages-2Mi: 768Mi
  ```

  The `limits` section defines the resource limits for the container. A container can't use more resources than what is defined in the limits. For more information, see Requests and limits.

  `aws.ec2.nitro/nitro_enclaves` is the resource name of the enclaves device driver defined in the device plugin. When the device plugin is registered, it advertises this name to kubelet. The resource name can be requested as part of a specification any time. In the template above, we specify 1 so that only one application can use the enclaves device driver at the same time. You can modify this value depending on your requirements.

  hugepages specifies the huge page size limit for your application. Nitro Enclaves uses large contiguous memory regions and therefore requires huge pages support. In the template above, the huge page size limit for the application is set to `768 MiB` of memory. Keep in mind that the `nitro-enclaves-allocator` service, which was installed to the node through the user data specified in the launch template, already allocated a huge page size based the value specified for `MEMORY_MIB` in the user data. For example, if the value for `MEMORY_MIB` in the user data is `1024`, the `nitro-enclaves allocator` allocated one page of 1 GiB huge page type for the whole node. In this case, the field in the deployment spec be defined as hugepages`-1Gi: 1Gi`.

  For more information, see Managing huge pages.

- ```
  requests:
    aws.ec2.nitro/nitro_enclaves: "1"
    hugepages-2Mi: 768Mi
  ```

  The `requests` section is used to define the node on which to place the pod For more information, see Requests and limits.

In the template above, we request a pod that has one enclave device (`aws.ec2.nitro/nitro_enclaves: "1"`), and a huge page size of 768 MiB (`hugepages-2Mi: 768Mi`).

The following is an example deployment specification for the Hello Enclaves application created in the previous steps.

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: hello_deployment
spec:
  replicas: 1
  selector:
    matchLabels:
      app: hello
  template:
    metadata:
      labels:
        app: hello
    spec:
      containers:
      - name: hello_container
        image: 123456789012.dkr.ecr.eu-central-1.amazonaws.com/hello-
b0f89e0a-7d83-4928-853c-9a3f941fa769:latest
        command: ["/home/run.sh"]
        resources:
          limits:
            aws.ec2.nitro/nitro_enclaves: "1"
            hugepages-2Mi: 768Mi
            cpu: 250m
          requests:
            aws.ec2.nitro/nitro_enclaves: "1"
            hugepages-2Mi: 768Mi
        volumeMounts:
        - mountPath: /dev/hugepages
          name: hugepage
          readOnly: false
      volumes:
      - name: hugepage
        emptyDir:
          medium: HugePages-2Mi
```

```
      tolerations:
      - effect: NoSchedule
        operator: Exists
      - effect: NoExecute
        operator: Exists
```

2. If the `ENCLAVE_CPU_ADVERTISEMENT` feature flag has been set, then the workloads can request a specific amount of CPUs for their enclaves. The Kubernetes scheduler can place the workloads on the EKS worker nodes according to the available CPUs. For more information, see `aws-nitro-enclaves-k8s-device-plugin` documentation.

   Kubernetes workloads can request CPUs for their enclaves (for example, 2) by adding `aws.ec2.nitro/nitro_enclaves_cpus: "2"` to the limits and sections under resources.

```
resources:
  limits:
    aws.ec2.nitro/nitro_enclaves_cpus: "2"
  requests:
    aws.ec2.nitro/nitro_enclaves_cpus: "2"
```

   These values need to be combined with the limits and requests from the previous step. The following example shows a fully populated `resources` section for a Kubernetes pod requesting access to a single enclave that requires 2Gi of memory and access to 2 CPUs.

```
resources:
  limits:
    aws.ec2.nitro/nitro_enclaves: "1"
    aws.ec2.nitro/nitro_enclaves_cpus: "2"
    hugepages-1Gi: 2Gi
    cpu: 250m
  requests:
    aws.ec2.nitro/nitro_enclaves: "1"
    aws.ec2.nitro/nitro_enclaves_cpus: "2"
    hugepages-1Gi: 2Gi
```

3. Apply the deployment specification to the cluster and deploy the application. Use the `kubectl apply` command and specify the deployment specification file.

```
$ kubectl apply -f deployment_spec.yaml
```

> **Tip**
>
> The **enclavectl** tool automates and simplifies the steps required to deploy an application to a cluster. You can use the `enclavectl run --image` *`image_name`* command to automatically generate a deployment specification for your application and to automatically deploy it to your cluster. For example, `enclavectl run --image hello`. If you prefer automatically generate a deployment specification for your application, but deploy it manually, add the `--prepare-only` flag. For example, `enclavectl run --image hello --prepare-only`. Doing this will generate the deployment specification but it will not deploy the application to the cluster. Once the deployment specification has been generated, you can deploy the application using the `kubectl apply` command.

Cryptographic attestation

Attestation is a unique feature available to Nitro Enclaves. The enclave uses the attestation process to prove its identity and build trust with an external service.

The attestation process uses a series of measurements that are unique to an enclave. You can use these measurements to create access policies in external services to grant the enclave access to special cryptographic operations. For more information, see Where to get an enclave's measurements.

Using the Nitro Enclaves SDK, an enclave can request a signed attestation document from the Nitro Hypervisor that includes its unique measurements. This document can be attached to requests from the enclave to an external service. The external service can validate the measurements included in the attestation document against the values in the access policy to determine whether to grant the enclave access to the requested operation. For more information, see How to get an enclave's attestation document.

Topics

- Integration with AWS KMS
- Where to get an enclave's measurements
- How to get an enclave's attestation document
- Using cryptographic attestation with AWS KMS
- Getting started with cryptographic attestation using the KMS Tool sample application

Integration with AWS KMS

Nitro Enclaves includes built-in support for attestation with AWS KMS. AWS KMS has the ability to ingest attestation documents that are presented by an enclave. Using the AWS KMS APIs included in the Nitro Enclaves SDK, you can perform AWS KMS actions, such as **Decrypt**, **GenerateDataKey**, and **GenerateRandom** from within the enclave. For more information about using the KMS APIs with Nitro Enclaves, see the Nitro Enclaves SDK GitHub repo and the How Nitro Enclaves uses AWS KMS in the *AWS Key Management Service Developer Guide*.

For more information about how to use attestation with AWS KMS, see Using cryptographic attestation with AWS KMS. If you are using a third-party external service, you must implement

your own access policies and mechanisms for attestation using the attestation document and the enclave's measurements.

Where to get an enclave's measurements

An enclave's measurements includes a series of hashes and platform configuration registers (PCRs) that are unique to the enclave. An enclave has six measurements:

PCR	Hash of ...	Description
PCR0	Enclave image file	A contiguous measure of the contents of the image file, without the section data.
PCR1	Linux kernel and bootstrap	A contiguous measurement of the kernel and boot ramfs data.
PCR2	Application	A contiguous, in-order measurement of the user applications, without the boot ramfs.
PCR3	IAM role assigned to the parent instance	A contiguous measurement of the IAM role assigned to the parent instance. Ensures that the attestati on process succeeds only when the parent instance has the correct IAM role.
PCR4	Instance ID of the parent instance	A contiguous measurement of the ID of the parent instance. Ensures that the attestation process succeeds only when the parent instance has a specific instance ID.
PCR8	Enclave image file signing certificate	A measure of the signing certificate specified for the enclave image file. Ensures that the attestation process succeeds only when the enclave was

PCR	Hash of ...	Description
		booted from an enclave image file signed by a specific certificate.

Some of the measures are exposed when the enclave image file is built, while others need to be manually generated based on information about the parent instance.

Enclaves launched using the `--debug-mode` or `--attach-console` options generate attestation documents with PCR values made up entirely of zeroes.

PCRs

- PCR0, PCR1, and PCR2
- PCR3
- PCR4
- PCR8

PCR0, PCR1, and PCR2

PCR0, PCR1, and PCR2 are exposed when the enclave image file (`.eif`) is built. In other words, they are provided as part of the output of the nitro-cli build-enclave command.

For example, when building the enclave image file for the `hello-world` sample application, the output includes the following.

```
Enclave Image successfully created.
{
  "Measurements": {
    "HashAlgorithm": "Sha384 { ... }",
    "PCR0":
 "7fb5c55bc2ecbb68ed99a13d7122abfc0666b926a79d5379bc58b9445c84217f59cfdd36c08b2c79552928702efe2
    "PCR1":
 "235c9e6050abf6b993c915505f3220e2d82b51aff830ad14cbecc2eec1bf0b4ae749d311c663f464cde9f718acca5
    "PCR2":
 "0f0ac32c300289e872e6ac4d19b0b5ac4a9b020c98295643ff3978610750ce6a86f7edff24e3c0a4a445f2ff8a9ea
  }
}
```

PCR3

To further strengthen the security posture of the enclave, you can create and attach an instance profile to the parent instance. After you create the instance profile and associate an IAM role with it, you can generate a SHA384 hash based on the Amazon resource name (ARN) of the IAM role that's associated with the instance profile. You can then use the hash as PCR3 in the condition keys for your AWS KMS key policies. Doing this ensures that only enclaves running on an instance that has the correct IAM role can perform specific AWS KMS actions against a KMS key. For more information, see Using instance profiles in the *IAM User Guide*.

You can generate the hash using any tool that is capable of converting a string to a SHA384 hash.

For example, the following command generates a SHA384 hash for an IAM role with an ARN of `arn:aws:iam::123456789012:role/Webserver`.

> **Note**
>
> In this example, the hash is padded with 48 `null` (`\0`) characters.

```
$ ROLEARN="arn:aws:iam::123456789012:role/Webserver"; \
python -c"import hashlib, sys; \
h=hashlib.sha384(); h.update(b'\0'*48); \
h.update(\"$ROLEARN\".encode('utf-8')); \
print(h.hexdigest())"
```

Example output

```
$ 78fce75db17cd4e0a3fb8dad3ad128ca5e77edbb2b2c7f75329dccd99aa5f6ef4fc1f1a452e315b9e98f9e312e692
```

PCR4

PCR4 is based on a SHA384 of the instance ID of the parent instance. Therefore, you can generate the PCR after you have launched the parent instance.

You can generate this hash using any tool that is capable of converting a string to a SHA384 hash.

For example, the following command generates a SHA384 hash for a parent instance with an instance ID of `i-1234567890abcdef0`.

> **Note**
>
> In this example, the hash is padded with 48 `null` (`\0`) characters.

```
$ INSTANCE_ID="i-1234567890abcdef0"; \
python -c"import hashlib, sys; \
h=hashlib.sha384(); h.update(b'\0'*48); \
h.update(\"$INSTANCE_ID\".encode('utf-8')); \
print(h.hexdigest())"
```

Example output

```
$ 08f996b5d43e047a9eb51e7f548bfee7e164fd7dc8f65541f2ac09d6545ac812719327281c401a67a10fcba87ae79
```

PCR8

You can also sign the enclave image file using your signing certificate and your private key.

PCR8 is exposed only when building a signed enclave image file (`.eif`) . In other words it is provided as part of the output of the nitro-cli build-enclave command when the `--private-key` and `--signing-certificate` options are specified. Doing this creates a signed enclave image file.

Using PCR8 ensures that only enclaves booted from an enclave image file signed by a specific certificate can perform specific AWS KMS actions against a KMS key. It also enables you to build more flexible condition keys that remain effective even if the enclave image or parent instance is changed. We recommend that you use PCR3 and PCR8 together for the best flexibility.

You can use OpenSSL to generate a private key and signing certificate that can be used to sign an enclave image file.

To generate a private key and signing certificate

1. Generate the private key.

   ```
   $ openssl ecparam -name secp384r1 -genkey -out key_name.pem
   ```

   This command generates the private key needed for the `--private-key` option.

2. Generate a certificate signing request (CSR). You can customize the request information if needed.

```
$ openssl req -new -key key_name.pem -sha384 -nodes -subj "/CN=AWS/C=US/ST=WA/
L=Seattle/O=Amazon/OU=AWS" -out csr.pem
```

3. Generate a certificate based on the CSR. Specify the CSR, the private key, a name for the certificate, and the number of days for which the certificate is to remain valid.

> **Important**
>
> If you attempt to start an enclave with an enclave image file that is signed with a certificate that is no longer valid, the `nitro-cli run-enclave` command fails with errors E36, E39, and E11.

```
$ openssl x509 -req -days 20  -in csr.pem -out certificate.pem -sha384 -
signkey key_name.pem
```

This command generates the signing certificate needed for the `--signing-certificate` option.

For example, when building the enclave image file for the `hello-world` sample application and specifying a private key and signing certificate, the output includes the following.

```
$ nitro-cli build-enclave --docker-uri hello-world:latest --output-file hello-
signed.eif --private-key key_name.pem --signing-certificate certificate.pem
```

```
Enclave Image successfully created.
{
  "Measurements": {
    "HashAlgorithm": "Sha384 { ... }",
    "PCR0":
 "7fb5c55bc2ecbb68ed99a13d7122abfc0666b926a79d5379bc58b9445c84217f59cfdd36c08b2c79552928702efe2
    "PCR1":
 "235c9e6050abf6b993c915505f3220e2d82b51aff830ad14cbecc2eec1bf0b4ae749d311c663f464cde9f718acca5
    "PCR2":
 "0f0ac32c300289e872e6ac4d19b0b5ac4a9b020c98295643ff3978610750ce6a86f7edff24e3c0a4a445f2ff8a9ea
```

```
    "PCR8":
 "70da58334a884328944cd806127c7784677ab60a154249fd21546a217299ccfa1ebfe4fa96a163bf41d3bcfaebe68
  }
}
```

How to get an enclave's attestation document

An enclave's attestation document is generated by the Nitro Hypervisor. You can request an enclave's attestation document from inside the enclave only, using the `get-attestation-document` API, which is included in the Nitro Enclaves SDK. For more information, see AWS Nitro Enclaves SDK Github repository.

> **Important**
>
> Enclaves booted in debug mode generate attestation documents with PCRs that are made up entirely of zeros. These attestation documents can't be used for cryptographic attestation.

Using cryptographic attestation with AWS KMS

This section explains how to set up attestation to work with AWS Key Management Service. AWS KMS integrates with Nitro Enclaves to provide built-in attestation support.

Secret data preparation

Before using Nitro Enclaves with AWS KMS, it is important that you encrypt your sensitive data before sending it to the parent instance or the enclave. This section provides an overview of the steps needed to prepare your sensitive data for processing inside the enclave.

1. Create a AWS KMS key. For more information, see Creating Keys in the *AWS Key Management Service Developer Guide*.
2. Generate a plaintext and encrypted data key using the KMS key. For more information, see generate-data-key in the *AWS KMS AWS CLI Command Reference*.
3. Encrypt the secret data under the KMS key using the plaintext data key and a client-side cryptographic library, such as the AWS Encryption SDK. For more information, see Encrypt data with a data key in the *AWS Key Management Service Developer Guide*. You must modify the

KMS key policy to grant the IAM principal that you're using in your client permission to call the GenerateDataKey API action.

4. Upload the encrypted secret data and the encrypted data key to a storage location, such as Amazon S3. If you're using the AWS Encryption SDK, the encrypted data key is automatically included in the header of the encrypted message.

KMS key preparation

After you have created your KMS key and you have encrypted your sensitive data under it, you need to ensure that only the enclave can access it to decrypt the encrypted data.

AWS KMS enables you to create KMS key policies with condition keys that are based on an enclave's measurements. For more information about using condition keys in KMS key policies, see AWS KMS condition keys for AWS Nitro Enclaves in the *AWS Key Management Service Developer Guide*.

The Nitro Enclaves SDK includes some APIs (`kms-decrypt`, `kms-generate-data-key`, and `kms-generate-random`) that integrate with AWS KMS. When these APIs are called against a specific key, the enclave's attestation document, which includes its measurements, is attached to the request. AWS KMS receives the request and validates the measurements in the provided attestation document against the measurements specified in the condition keys of the KMS key policy. It uses this information to determine whether the enclave should be granted permission to perform the requested action using the requested KMS key.

To prepare AWS KMS for attestation you must have the enclave's measurements. When you have the measurements, you can create a KMS key policy that includes condition keys that are based on those measurements.

AWS KMS provides `kms:RecipientAttestation:ImageSha384` and `kms:RecipientAttestation:PCR` condition keys that enable you to create attestation-based condition keys for KMS key policies. These policies ensure that AWS KMS only allows operations using the KMS key if the enclave provides a signed attestation document that contains measurements that match the measurements specified in the KMS key policy's condition keys. For more information about the condition keys, see kms:RecipientAttestation:ImageSha384 and kms:RecipientAttestation:PCR in the *AWS Key Management Service Developer Guide*.

For example, the following KMS key policy allows enclaves running on instances that have the `data-processing` instance profile to use the KMS key for the `Decrypt`, `GenerateDataKey`, and `GenerateRandom` actions. The condition key allows the operation only when measurements in the

attestation document in the request matches the measurements in the condition. If the request doesn't include an attestation document, the role doesn't have permission to call the operation because this condition cannot be satisfied.

JSON

```
{
  "Version":"2012-10-17",
  "Statement": [{
    "Sid" : "Enable enclave data processing",
    "Effect" : "Allow",
    "Principal" : {
      "AWS" : "arn:aws:iam::123456789012:role/data-processing"
    },
    "Action": [
      "kms:Decrypt",
      "kms:GenerateDataKey",
      "kms:GenerateRandom"
    ],
    "Resource": "*",
    "Condition": {
      "StringEqualsIgnoreCase": {

 "kms:RecipientAttestation:ImageSha384":"EXAMPLE8abcdef7abcdef6abcdef5abcdef4abcdef3abcde

 "kms:RecipientAttestation:PCR0":"EXAMPLE8abcdef7abcdef6abcdef5abcdef4abcdef3abcdef2abcde

 "kms:RecipientAttestation:PCR1":"EXAMPLE050abf6b993c915505f3220e2d82b51aff830ad14cbecc2e

 "kms:RecipientAttestation:PCR2":"EXAMPLEc300289e872e6ac4d19b0b5ac4a9b020c98295643ff39786

 "kms:RecipientAttestation:PCR3":"EXAMPLE11de9baee597508183477f097ae385d4a2c885aa65543236

 "kms:RecipientAttestation:PCR4":"EXAMPLE6b9b3d89a53b13f5dfd14a1049ec0b80a9ae4b159adde479

 "kms:RecipientAttestation:PCR8":"EXAMPLE34a884328944cd806127c7784677ab60a154249fd21546a2
      }
    }
  }]
}
```

Getting started with cryptographic attestation using the KMS Tool sample application

The AWS Nitro Enclaves SDK ships with a sample application, called **KMS Tool**, that demonstrates the cryptographic attestation process. The KMS Tool sample application is supported on both Windows and Linux parent instances.

KMS Tool includes two applications:

- **kmstool-instance**—An application that runs on the parent instance. It connects to *kmstool-enclave* (over the vsock socket), passes credentials to the enclave, along with a base64-encoded message for decryption.
- **kmstool-enclave**—An application that runs in an enclave. It uses the Nitro Enclaves SDK to call AWS KMS in order to decrypt the base64-encoded message received from the application running on the parent instance.

For instructions on how to set up and use the KMS Tool sample application, see the tutorial in the AWS Nitro Enclaves SDK Github repository. This tutorial shows you how to:

- Launch an enclave-enabled parent instance.
- Build a Docker image from a Docker file.
- Convert a Docker image to an enclave image file.
- Create an AWS KMS key.
- Add attestation-based condition keys to a KMS key policy.
- Create an enclave using an enclave image file.

> **Tip**
>
> The tutorial also discusses some best practices for preparing your enclave and KMS key for attestation. You can use this sample application as a reference for building your own enclave applications and for preparing your enclave and KMS keys for attestation.

Verifying the root of trust

> **Note**
>
> This topic is intended for users who are using a third-party key management service, and need to build their own attestation document validation processes.

This topic provides a detailed overview of the entire Nitro Enclaves attestation flow. It also discusses what is generated by the AWS Nitro system when an attestation document is requested, and explains how a key management service should process an attestation document.

Topics

- Attestation in the Nitro Enclaves world
- The attestation document
- Attestation document validation

Attestation in the Nitro Enclaves world

The purpose of attestation is to prove that an enclave is a trustworthy entity, based on the code and configuration that is running within a particular enclave. The root of trust for the enclave resides within the AWS Nitro system, which provides attestation documents to the enclave.

The root of trust component for the attestation is the Nitro Hypervisor, which contains information about the enclave, such as its platform configuration registers (PCRs). The Nitro Hypervisor is able to produce an attestation document that contains details of the enclave, including the enclave signing key, a hash of the enclave image, a hash of the parent instance ID, and a hash of the ARN of the attached IAM role.

Attestation documents are signed by the AWS Nitro Attestation Public Key Infrastructure (PKI), which includes a published certificate authority that can be incorporated into any service.

The attestation document

An enclave can request an attestation document from the Nitro hypervisor that it can use to verify its identity with an external service. The attestation document that is generated by the Nitro

system is encoded in Concise Binary Object Representation (CBOR), and it is signed using CBOR Object Signing and Encryption (COSE).

For more information about CBOR, see RFC 8949: Concise Binary Object Representation (CBOR). For more information about the COSE implementation, see the COSE for AWS Nitro Enclaves Github repository.

Attestation document specification

The following shows the structure of an attestation document.

```
AttestationDocument = {
    module_id: text,                ; issuing Nitro hypervisor module ID
    timestamp: uint .size 8,        ; UTC time when document was created, in
                                    ; milliseconds since UNIX epoch
    digest: digest,                 ; the digest function used for calculating the
                                    ; register values
    pcrs: { + index => pcr },       ; map of all locked PCRs at the moment the
                                    ; attestation document was generated
    certificate: cert,              ; the public key certificate for the public key
                                    ; that was used to sign the attestation document
    cabundle: [* cert],             ; issuing CA bundle for infrastructure certificate
    ? public_key: user_data,        ; an optional DER-encoded key the attestation
                                    ; consumer can use to encrypt data with
    ? user_data: user_data,         ; additional signed user data, defined by protocol
    ? nonce: user_data,             ; an optional cryptographic nonce provided by the
                                    ; attestation consumer as a proof of authenticity
}

cert = bytes .size (1..1024)        ; DER encoded certificate
user_data = bytes .size (0..1024)
pcr = bytes .size (32/48/64)        ; PCR content
index = 0..31
digest = "SHA384"
```

The enclave and the service that wants to attest the enclave first need to agree on a common protocol to follow. The optional parameters in the attestation document (`public_key`, `user_data`, and `nonce`) allow the enclave and the entity to set up a variety of protocols depending on the security properties that the service and the enclave want to guarantee. Services that rely on attestation need to define a protocol that can meet those guarantees, and the enclave software needs to agree to and follow these protocols.

An enclave wishing to attest to a specific service first has to open a TLS connection to that service and verify that the service's certificates are valid. These certificates must then be included in the enclave during the enclave image file build.

> **Note**
>
> A TLS session is not absolutely required, but it does provide integrity of data between the enclave and the third-party service.

For more information about the optional fields in the attestation document, see the Nitro Enclaves Attestation Process.

Attestation document validation

When you request an attestation document from the Nitro Hypervisor, you receive a binary blob that contains the signed attestation document. The signed attestation document is a CBOR-encoded, COSE-signed (using the COSE_Sign1 signature structure) object. The overall validation process includes the following steps:

1. Decode the CBOR object and map it to a COSE_Sign1 structure.
2. Extract the attestation document from the COSE_Sign1 structure.
3. Verify the certificate's chain.
4. Ensure that the attestation document is properly signed.

Attestation documents are signed by the AWS Nitro Attestation PKI, which includes a root certificate for the commercial AWS partitions. The root certificate can be downloaded from https://aws-nitro-enclaves.amazonaws.com/AWS_NitroEnclaves_Root-G1.zip, and it can be verified using the following fingerprint.

```
64:1A:03:21:A3:E2:44:EF:E4:56:46:31:95:D6:06:31:7E:D7:CD:CC:3C:17:56:E0:98:93:F3:C6:8F:79:BB:5B
```

The root certificate is based on an AWS Certificate Manager Private Certificate Authority (AWS Private CA) private key and it has a lifetime of 30 years. The subject of the PCA has the following format.

```
CN=aws.nitro-enclaves, C=US, O=Amazon, OU=AWS
```

Topics

- COSE and CBOR
- Semantical validity
- Certificate validity
- Certificate chain validity

COSE and CBOR

Usually, the COSE_Sign1 signature structure is used when only one signature is going to be placed on a message. The parameters dealing with the content and the signature are placed in the protected header rather than having the separation of COSE_Sign. The structure can be encoded as either tagged or untagged, depending on the context it will be used in. A tagged COSE_Sign1 structure is identified by the CBOR tag 18.

The CBOR object that carries the body, the signature, and the information about the body and signature is called the COSE_Sign1 structure. The COSE_Sign1 structure is a CBOR array. The array includes the following fields.

```
[
  protected:   Header,
  unprotected: Header,
  payload:     This field contains the serialized content to be signed,
  signature:   This field contains the computed signature value.
]
```

In the context of an attestation document, the array includes the following.

```
18(/* COSE_Sign1 CBOR tag is 18 */
    {1: -35}, /* This is equivalent with {algorithm: ECDS 384} */
    {}, /* We have nothing in unprotected */
    $ATTESTATION_DOCUMENT_CONTENT /* Attestation Document */,
    signature /* This is the signature */
)
```

For more information about CBOR, see RFC 8949: Concise Binary Object Representation (CBOR). For more information about the COSE implementation, see the COSE for AWS Nitro Enclaves Github repository.

Semantical validity

An attestation document will always have its CA bundle in the following order.

```
[ ROOT_CERT - INTERM_1 - INTERM_2 .... - INTERM_N]
      0          1          2             N - 1
```

Keep this ordering in mind, as some existing tools, such as Java's CertPath from Java PKI API Programmer's Guide, might require them to be ordered differently.

To validate the certificates, start from the attestation document CA bundle and generate the required chain, Where `TARGET_CERT` is the certificate in the attestation document.

```
[TARGET_CERT, INTERM_N, ..... , INTERM_2, INTERM_1, ROOT_CERT]
```

For more information about the optional fields in the attestation document, see the Nitro Enclaves Attestation Process.

Certificate validity

For all of the certificates in the chain, you must ensure that the current date falls within the validity period specified in the certificate.

Certificate chain validity

In general, a chain of multiple certificates might be needed, comprising a certificate of the public key owner signed by one CA, and zero or more additional certificates of CAs signed by other CAs. Such chains, called certification paths, are required because a public key user is only initialized with a limited number of assured CA public keys. Certification path validation procedures for the internet PKI are based on the algorithm supplied in X.509. Certification path processing verifies the binding between the subject distinguished name and/or subject alternative name and subject public key. The binding is limited by constraints that are specified in the certificates that comprise the path and inputs that are specified by the relying party. The basic constraints and policy constraint extensions allow the certification path processing logic to automate the decision making process.

> **Note**
>
> CRL must be disabled when doing the validation.

Using Java, starting from the root path and the generated certificate chain, the chain validation is as follows.

```
validateCertsPath(certChain, rootCertficate) {
    /* The trust anchor is the root CA to trust */
    trustAnchors.add(rootCertificate);

    /* We need PKIX parameters to specify the trust anchors
     * and disable the CRL validation
     */
    validationParameters = new PKIXParameters(trustAnchors);
    certPathValidator = CertPathValidator.getInstance(PKIX);
    validationParameters.setRevocationEnabled(false);

    /* We are ensuring that certificates are chained correctly */
    certPathValidator.validate(certPath, validationParameters);
}
```

AWS Certificate Manager for Nitro Enclaves

AWS Certificate Manager (ACM) for Nitro Enclaves allows you to use public and private SSL/TLS certificates with your web applications and web servers running on Amazon EC2 instances with AWS Nitro Enclaves. SSL/TLS certificates are used to secure network communications and to establish the identity of websites over the internet, as well as resources on private networks.

Previously, when running a web server on an EC2 instance, you would have created SSL certificates and stored them as plaintext on your instance. With ACM for Nitro Enclaves, you can now bind AWS Certificate Manager certificates to an enclave and use those certificates directly with your web server, without exposing the certificates in plaintext form to the parent instance and its users.

ACM for Nitro Enclaves removes the time-consuming and error-prone manual process of purchasing, uploading, and renewing SSL/TLS certificates. ACM for Nitro Enclaves creates secure private keys, distributes the certificate and its private key to your enclave, and manages certificate renewals. With ACM for Nitro Enclaves, the certificate's private key remains isolated in the enclave, preventing the instance, and its users, from accessing it.

Currently, ACM for Nitro Enclaves works with NGINX servers and Apache HTTP servers running on Amazon EC2 instances to install the certificate and seamlessly replace expiring certificates. Support for additional web servers will be added over time.

> **Note**
>
> ACM for Nitro Enclaves uses the standardized PKCS11 cryptographic interface between the parent instance and the enclave. Any application that supports the PKCS11 protocol can be adapted to use ACM for Nitro Enclaves for protecting certificates and keys.
> ACM for Nitro Enclaves also includes a “helper” `p11-kit` based module for using the PKCS11 protocol over the Nitro Enclaves vsock socket.

Contents

- Pricing and billing
- Considerations
- Install ACM for Nitro Enclaves
- Update ACM for Nitro Enclaves

- Uninstall ACM for Nitro Enclaves

Pricing and billing

Public SSL/TLS certificates that you provision through ACM for Nitro Enclaves are available at no additional cost. You pay only for the AWS resources that you create to run your application, such as Amazon EC2 instances. Private certificates are available at no additional cost per certificate when you use and pay for ACM Private CA.

Considerations

The following considerations apply when using ACM for Nitro Enclaves:

- ACM for Nitro Enclaves only supports RSA certificates.
- ACM for Nitro Enclaves is available for Linux instances only. It is currently not supported on Windows instances.
- ACM for Nitro Enclaves is currently not supported in the following Regions: Asia Pacific (Hyderabad), Asia Pacific (Jakarta), Asia Pacific (Malaysia), Asia Pacific (Melbourne), Asia Pacific (New Zealand), Asia Pacific (Osaka), Asia Pacific (Taipei), Asia Pacific (Thailand), Canada West (Calgary), Europe (Spain), Europe (Zurich), Israel (Tel Aviv), and Mexico (Central).

Install ACM for Nitro Enclaves

Use the following procedure to install and configure ACM for Nitro Enclaves.

Steps

- Step 1: Create the ACM certificate
- Step 2: Prepare the enclaves-enabled parent instance
- Step 3: Prepare the IAM role
- Step 4: Associate the role with the ACM certificate
- Step 5: Grant the role permission to access the certificate and encryption key
- Step 6: Attach the role to the instance
- Step 7: Configure the web server to use ACM for Nitro Enclaves

- Using multiple certificates

Prerequisites

The user performing this configuration must have permission to use the `ec2:AssociateEnclaveCertificateIamRole`, `ec2:GetAssociatedEnclaveCertificateIamRoles`, and `ec2:DisassociateEnclaveCertificateIamRole` actions. To grant the user the required permissions, use the following IAM policy.

JSON

```
{
    "Version":"2012-10-17",
    "Statement": [
        {
            "Action": [
                "ec2:AssociateEnclaveCertificateIamRole",
                "ec2:GetAssociatedEnclaveCertificateIamRoles",
                "ec2:DisassociateEnclaveCertificateIamRole"
            ],
            "Resource": [
                "arn:aws:acm:us-east-1:111122223333:certificate/*",
                "arn:aws:iam::111122223333:role/*"
            ],
            "Effect": "Allow"
        }
    ]
}
```

Step 1: Create the ACM certificate

Create the AWS Certificate Manager (ACM) certificate that you want use with your NGINX or Apache HTTP server. ACM for Nitro Enclaves supports both private and public certificates. For more information about creating a certificate, see the following resources in the *AWS Certificate Manager User Guide*.

- Requesting a Public Certificate
- Requesting a Private Certificate

When you use DNS validation to request an ACM certificate, ACM provides a CNAME record that you must then add to your DNS configuration. ACM uses the CNAME record to validate ownership of domains.

Step 2: Prepare the enclaves-enabled parent instance

Launch the enclave enabled instance that you will use as the parent instance. You can use either the ACM for Nitro Enclaves AMI from AWS Marketplace, or you can install ACM for Nitro Enclaves and the web server using RPM packages.

> **Tip**
>
> After you launch the instance, make a note of the instance ID, as you'll need it later.

Option 1: Using ACM for Nitro Enclaves AMI

To launch an instance using the ACM for Nitro Enclaves AMI from AWS Marketplace

1. Open the ACM for Nitro Enclaves page in the AWS Marketplace.
2. Find the ACM for Nitro Enclaves AMI for your Region, and note the AMI ID. You need the AMI ID for the next step.
3. Launch the instance using the AMI from the AWS Marketplace and enable it for Nitro Enclaves using the following command.

```
$ aws ec2 run-instances --image-id ami_id --count 1 --instance-
type supported_instance_type --key-name your_key_pair --enclave-options
 'Enabled=true'
```

Option 2: Using RPM packages

To install ACM for Nitro Enclaves from the Amazon Linux Extras repository

1. Connect to the instance.
2. Enable the `aws-nitro-enclaves-cli` topic in the Amazon Linux Extras library.

```
$ sudo amazon-linux-extras enable aws-nitro-enclaves-cli
```

3. Install your preferred web server. Do one of the following:

   - **NGINX**

     Enable the `nginx1` topic in the Amazon Linux Extras library and install NGINX from the Amazon Linux Extras library.

     ```
     $ sudo amazon-linux-extras enable nginx1
     ```

     ```
     $ sudo amazon-linux-extras install nginx1 -y
     ```

   - **Apache**

     Install and configure the Apache HTTP server with SSL/TLS support.

     ```
     $ sudo yum -y install httpd mod_ssl
     ```

4. Install ACM for Nitro Enclaves from the Amazon Linux Extras library.

   ```
   $ sudo yum install aws-nitro-enclaves-acm -y
   ```

Step 3: Prepare the IAM role

To grant the instance permission to use the ACM certificate, you must create an IAM role with the required permissions. The IAM role is later attached to the instance and the ACM certificate.

Create a JSON file named `acm-role` and add the following policy statement.

JSON

```
{
   "Version":"2012-10-17",
   "Statement":[
      {
         "Effect":"Allow",
         "Principal":{
            "Service":"ec2.amazonaws.com"
         },
         "Action":"sts:AssumeRole"
```

```
        }
    ]
}
```

Use the create-role command to create a role named `acm-role`, and specify the path to the JSON policy file.

```
$ aws iam create-role --role-name acm-role --assume-role-policy-document file://acm-role.json
```

After you have created the role, make a note of the role ARN, as you'll need it in the next step.

Step 4: Associate the role with the ACM certificate

Attach the IAM role that you created in the previous step to the ACM certificate. To do this, use the associate-enclave-certificate-iam-role command, and specify the ARN of the role to attach, and the ARN of the certificate to attach it to.

```
$ aws ec2 --region region associate-enclave-certificate-iam-role --certificate-arn certificate_ARN --role-arn role_ARN
```

For example

```
$ aws ec2 --region us-east-1 associate-enclave-certificate-iam-role --certificate-arn
 arn:aws:acm:us-east-1:123456789012:certificate/d4c3b2a1-e5d0-4d51-95d9-1927fEXAMPLE --role-arn arn:aws:iam::123456789012:role/acm-role
```

Example output

```
{

"CertificateS3BucketName": "aws-ec2-enclave-certificate-us-east-1-prod",
"CertificateS3ObjectKey": "arn:aws:iam::123456789012:role/acm-role/arn:aws:acm:us-east-1:123456789012:certificate/d4c3b2a1-e5d0-4d51-95d9-1927fEXAMPLE",
"EncryptionKmsKeyId": "a1b2c3d4-354d-4e51-9190-b12ebEXAMPLE"
}
```

After running the command, make a note of `CertificateS3BucketName` and `EncryptionKmsKeyId`, as you'll need them for the next step.

Step 5: Grant the role permission to access the certificate and encryption key

You must now grant the IAM role (`acm-role`) permission to do the following:

- Retrieve the ACM certificate from the Amazon S3 bucket returned in the previous step
- Perform `kms:Decrypt` using the AWS KMS key returned in the previous step
- Retrieve information about itself, including its path, GUID, and ARN.

Create a JSON file named `acm-role-policies.json`, add the following policy statement, and specify the values of `CertificateS3BucketName` and `EncryptionKmsKeyId` from the previous step.

JSON

```
{
    "Version":"2012-10-17",
    "Statement": [
        {
            "Effect": "Allow",
            "Action": [
                "s3:GetObject"
            ],
            "Resource": [
                "arn:aws:s3:::CertificateS3BucketName/*"
            ]
        },
        {
            "Sid": "VisualEditor0",
            "Effect": "Allow",
            "Action": [
                "kms:Decrypt"
            ],
            "Resource": "arn:aws:kms:us-east-1:*:key/EncryptionKmsKeyId"
        },
        {
            "Effect": "Allow",
            "Action": "iam:GetRole",
            "Resource": "arn:aws:iam::123456789012:role/acm-role"
        }
```

```
    ]
}
```

Use the put-role-policy command to add the additional policies to the `acm-role` role, and specify the path to the JSON policy file.

```
$ aws iam put-role-policy --role-name acm-role --policy-name acm-role-policy --policy-
document file://acm-role-policies.json
```

Step 6: Attach the role to the instance

You must attach the IAM role to the instance to give it permission to use the certificate.

Create a new instance profile named `acm-instance-profile` using the create-instance-profile command.

```
$ aws iam create-instance-profile --instance-profile-name acm-instance-profile
```

Example output

```
{
    "InstanceProfile": {
    "Path": "/",
     "InstanceProfileName": "acm-instance-profile",
    "InstanceProfileId": "ABCDUS6G56GWDIEXAMPLE",
    "Arn": "arn:aws:iam::123456789012:instance-profile/acm-instance-profile",
    "CreateDate": "2020-10-14T03:38:08+00:00",
"Roles": []
}
}
```

Add the `acm-role` that you created earlier to the `acm-instance-profile` that you just created. Use the add-role-to-instance-profile command.

```
$ aws iam add-role-to-instance-profile --instance-profile-name acm-instance-profile --
role-name acm-role
```

Associate the instance profile with the instance that you launched previously. Use the associate-iam-instance-profile command and specify the instance profile to attach and the instance to attach it to.

```
$ aws ec2 --region region associate-iam-instance-profile --instance-id instance_id --
iam-instance-profile Name=acm-instance-profile
```

Example output

```
{
    "IamInstanceProfileAssociation":
    {
        "AssociationId": "iip-assoc-0a411083b4EXAMPLE",
        "InstanceId": "i-1234567890abcdef0",
        "IamInstanceProfile":
        {
            "Arn": "arn:aws:iam::123456789012:instance-profile/acm-instance-profile",
            "Id": "ABCDUS6G56GWDIEXAMPLE"
        },
        "State": "associating"
    }
}
```

Step 7: Configure the web server to use ACM for Nitro Enclaves

Configure the NGINX or Apache HTTP web server to use the ACM certificate. Choose the correct procedure depending on the web server you're using.

NGINX

To configure NGINX

1. SSH into the instance that you launched previously.
2. Nitro Enclaves ships with a sample ACM for Nitro Enclaves configuration file that you can use as a starting point for your own configuration. To use the sample configuration file, rename the configuration file from `/etc/nitro_enclaves/acm.example.yaml` to `/etc/nitro_enclaves/acm.yaml`.

   ```
   $ sudo mv /etc/nitro_enclaves/acm.example.yaml /etc/nitro_enclaves/acm.yaml
   ```

3. Specify the ARN of the certificate that you associated with the IAM role that is attached to the parent instance. Using your preferred text editor, open `/etc/nitro_enclaves/acm.yaml`. In the `Acm` section, for `certificate_arn`, specify the ARN of the certificate. Save and close the file.
4. Open the `/etc/httpd/conf.d/ssl.conf` file and find this directive:

   ```
   SSLCryptoDevice builtin
   ```

   Change the directive as follows:

   ```
   SSLCryptoDevice pkcs11
   ```

5. Configure NGINX to use the pkcs11 SSL engine by setting the top-level `ssl_engine` directive.

   Using your preferred text editor, open `/etc/nginx/nginx.conf`. Add the following line below `pid /run/nginx.pid;`.

   ```
   ssl_engine pkcs11;
   ```

   Example

   ```
   # For more information on configuration, see:
   #   * Official English Documentation: http://nginx.org/en/docs/

   user nginx;
   worker_processes auto;
   error_log /var/log/nginx/error.log;
   pid /run/nginx.pid;

   ssl_engine pkcs11;
   ```

6. Enable the TLS server and configure the server to use your certificate.

   In `/etc/nginx/nginx.conf`, scroll to the bottom of the file and do the following:

   - Uncomment all of the lines below `Settings for a TLS enabled server`.
   - In the first block, for `server_name`, specify the host name, or the common name (CN), that you specified when you created the certificate.

- In the second block, remove the following lines.

```
ssl_certificate "/etc/pki/nginx/server.crt";
ssl_certificate_key "/etc/pki/nginx/private/server.key";
ssl_ciphers PROFILE=SYSTEM;
```

  And add the following line.

```
ssl_protocols TLSv1.2;
```

- Add the following as a new block below the second block.

```
# Set this to the stanza path configured in /etc/nitro_enclaves/acm.yaml
include "/etc/pki/nginx/nginx-acm.conf";
```

The completed section should appear as follows.

```
# Settings for a TLS enabled server.
#
    server {
        listen       443 ssl http2;
        listen       [::]:443 ssl http2;
        server_name  example.com;
        root         /usr/share/nginx/html;

        ssl_protocols TLSv1.2;
        ssl_session_cache shared:SSL:1m;
        ssl_session_timeout  10m;
        ssl_prefer_server_ciphers on;

        # Set this to the stanza path configured in /etc/nitro_enclaves/acm.yaml
        include "/etc/pki/nginx/nginx-acm.conf";

        # Load configuration files for the default server block.
        include /etc/nginx/default.d/*.conf;

        error_page 404 /404.html;
            location = /40x.html {
        }
        error_page 500 502 503 504 /50x.html;
            location = /50x.html {
```

```
        }
    }
```

- (Amazon Linux 2023) Edit the OpenSSL configuration file `/etc/pki/tls/openssl.cnf` as follows.

```
[openssl_init]
...
engines = engine_section

[engine_section]
pkcs11 = pkcs11_section

[ pkcs11_section ]
engine_id = pkcs11
init = 1
...
```

7. Start the ACM for Nitro Enclaves service and ensure that it starts automatically at instance boot.

```
$ sudo systemctl start nitro-enclaves-acm.service
```

```
$ sudo systemctl enable nitro-enclaves-acm
```

8. Test that the ACM for Nitro Enclaves is working as expected.

   If you used a public certificate, use the following command.

```
$ curl https://host_name_or_IP
```

   If you used a private certificate, you must add the host name to `/etc/hosts` in the following format: `127.0.0.1` *`host_name`*, for example `127.0.0.1 example.com`. And you must specify the certificate chain to use to validate the certificate. For more information about generating the certificate chain for your certificate, see Exporting a Private Certificate in the *AWS Certificate Manager User Guide*.

```
$ curl --cacert path_to_pem_file https://host_name_or_IP
```

A successful test displays the NGINX index.htm. The ACM for Nitro Enclaves service continuously polls and fetches the ACMcertificate data and updates NGINX accordingly. It does this by generating an NGINX config snippet and including it in the main `nginx.conf`.

If you renew the ACM certificate by running acm renew-certificate, the ACM for Nitro Enclaves automatically reconfigures the enclave and the NGINX web server. You can use the following command to check the log for update announcements and to diagnose possible issues.

```
$ journalctl -u nitro-enclaves-acm.service
```

If you encounter any unexpected errors, you can also check the NGINX service log for more details.

```
$ journalctl -u nginx.service
```

Apache

To configure Apache HTTP server

1. SSH into the instance that you launched previously.
2. Nitro Enclaves ships with a sample ACM for Nitro Enclaves configuration file that you can use as a starting point for your own configuration. Rename the sample ACM for Nitro Enclaves configuration file from `/etc/nitro_enclaves/acm-httpd.example.yaml` to `/etc/nitro_enclaves/acm.yaml`.

   ```
   $ sudo mv /etc/nitro_enclaves/acm-httpd.example.yaml /etc/nitro_enclaves/
   acm.yaml
   ```

3. Specify the ARN of the certificate that you associated with the IAM role that is attached to the parent instance. Using your preferred text editor, open `/etc/nitro_enclaves/acm.yaml`. In the `Acm` section, for `certificate_arn`, specify the ARN of the certificate. Save and close the file.
4. Using your preferred text editor, open `/etc/httpd/conf.d/httpd-acm.conf`. For `ServerName`, specify the host name, or the common name (CN), that you specified when

you created the certificate, and configure the remaining settings as needed. The following is an example of a minimal SSL/TLS configuration:

```
<VirtualHost *:443>
ServerName www.example.com
SSLEngine on
SSLProtocol -all +TLSv1.2
SSLCertificateKeyFile "/etc/pki/tls/private/localhost.key"
SSLCertificateFile "/etc/pki/tls/certs/localhost.crt"
</VirtualHost>
```

> **Note**
>
> The `SSLCertificateFile` and `SSLCertificateKeyFile` entries must be present in the configuration file. These entries will be automatically updated with the URIs after starting the ACM for Nitro Enclaves service.

5. Apache HTTP server ships with a configuration file that you can use. To use the configuration file, rename it from `/etc/httpd/conf.d/ssl.conf` to `/etc/httpd/conf.d/httpd-acm.conf`.

```
$ sudo mv /etc/httpd/conf.d/ssl.conf /etc/httpd/conf.d/httpd-acm.conf
```

6. Start the ACM for Nitro Enclaves service and ensure that it starts automatically at instance boot.

```
$ sudo systemctl start nitro-enclaves-acm.service
```

```
$ sudo systemctl enable nitro-enclaves-acm
```

7. Test that the ACM for Nitro Enclaves is working as expected.

   - If you used a public certificate, use the following command.

     ```
     $ curl https://host_name_or_IPM
     ```

   - If you used a private certificate, you must add the host name to `/etc/hosts` in the following format: 127.0.0.1 *host_name*, for example `127.0.0.1 example.com`. And you must specify the certificate chain to use to validate the certificate. For more

information about generating the certificate chain for your certificate, see Exporting a Private Certificate in the *AWS Certificate Manager User Guide*.

```
$ curl --cacert path_to_pem_file https://host_name_or_IP
```

A successful test displays the Apache HTTP index.htm. The ACM for Nitro Enclaves service continuously polls and fetches the ACM certificate data and updates Apache accordingly.

If you renew the ACM certificate by running acm renew-certificate, the ACM for Nitro Enclaves automatically reconfigures the enclave and the Apache web server. You can use the following command to check the log for update announcements and to diagnose possible issues.

```
$ $ journalctl -u nitro-enclaves-acm.service
```

If you encounter any unexpected errors, you can also check the Apache HTTP service log for more details.

```
$ journalctl -u httpd.service
```

Using multiple certificates

You can also add multiple ACM certificates; one for each PKCS#11 token. For each additional certificate that you need to add, repeat Step 4: Associate the role with the ACM certificate in order to associate your IAM role with the additional ACM certificates.

Then to add more PKCS#11 tokens, open `/etc/nitro_enclaves/acm.yaml` with your preferred text editor, and under the `token` section, add another `label` block and specify a label name, the ARN of the additional certificate, and a path for the NGINX stanza or Apache HTTP configuration file respectively. For example, the following snippet shows the format to be used for two ACM certificates (the initial certificate and two additional certificates):

NGINX

```
tokens:
    # A label for this PKCS#11 token
  - label: nginx-acm-token
```

```
    # Configure a managed token, sourced from an ACM certificate.
    source:
      Acm:
        # The certificate ARN
        # Note: this certificate must have been associated with the IAM role
 assigned to the instance on
        # which ACM for Nitro Enclaves is run.
        certificate_arn: "arn:aws:acm:us-east-1:123456789012:certificate/d4c3b2a1-
e5d0-4d51-95d9-1927fEXAMPLE"
    target:
      NginxStanza:
        # Path to the nginx stanza to be written by the ACM service whenever # the
 certificate configuration
        # changes (e.g. after a certificate renewal). # This file must be included
 from the main nginx config
        # `server` section, as it will contain the TLS nginx configuration
 directives.
        path: /etc/pki/nginx/nginx-acm.conf
        # Stanza file owner (i.e. the user nginx is configured to run as).
        user: nginx
    # PKCS#11 token 2
  - label: token_2_name
    source:
      Acm:
        certificate_arn: "certificate_2_ARN"
    target:
      NginxStanza:
        path: /etc/pki/nginx/nginx-acm-2.conf
        user: nginx
```

Apache

```
tokens:
  # A label for this PKCS#11 token
  - label: token_1_name
    # Configure a managed token, sourced from an ACM certificate.
    source:
      Acm:
        # The certificate ARN
        # Note: this certificate must have been associated with the IAM role
 assigned to the instance
        # on which ACM for Nitro Enclaves is run.
        certificate_arn: "certificate_1_ARN"
```

```
    target:
      Conf:
        # Path to the server configuration file to be written by # the ACM service
whenever the
        # certificate configuration changes (e.g. after a certificate renewal). The
SSLCertificateKeyFile
        # and optionally the SSLCertificateFile directives shall be populated.
        path: /etc/httpd/conf.d/httpd-acm.conf
        # Configuration file owner (i.e. the user httpd is configured to run as).
        user: apache
    # Attestation period (seconds)
    refresh_interval_secs: 43200

  - label: token_2_name
    # Configure a managed token, sourced from an ACM certificate.
    source:
      Acm:
        # The certificate ARN
        # Note: this certificate must have been associated with the IAM role
assigned to the instance
        # on which ACM for Nitro Enclaves is run.
        certificate_arn: "certificate_2_ARN"
    target:
      Conf:
        # Path to the server configuration file to be written by the ACM service
whenever the certificate
        # configuration changes (e.g. after a certificate renewal). The
SSLCertificateKeyFile and optionally
        # the SSLCertificateFile directives shall be populated.
        path: /etc/httpd/conf.d/httpd-acm-2.conf
        # Configuration file owner (i.e. the user httpd is configured to run as).
        user: apache
    # Attestation repeat period (seconds)
    refresh_interval_secs: 43200
```

Note

You also need to update the `/etc/nginx/nginx.conf` configuration (NGINX) or the `/etc/httpd/conf.d/httpd-acm.conf` configuration file (Apache) to include the additional ACM certificates. For more information about configuring NGINX for multiple

domains and about different use cases, refer to the NGINX documentation or Apache HTTP server documentation.

After you have completed the necessary configuration, run the following command to restart the Start the ACM for Nitro Enclaves service.

```
$ sudo systemctl restart nitro-enclaves-acm.service
```

Update ACM for Nitro Enclaves

If you have already installed *AWS Certificate Manager for Nitro Enclaves*, use the following command to update it to the latest version.

```
$ sudo yum update aws-nitro-enclaves-acm
```

Uninstall ACM for Nitro Enclaves

If you no longer want to use *AWS Certificate Manager for Nitro Enclaves*, use the following procedure to uninstall it.

To uninstall ACM for Nitro Enclaves

1. Stop the web server.

   - **NGINX**

     ```
     $ sudo systemctl stop nginx
     ```

   - **Apache**

     ```
     $ sudo systemctl stop httpd
     ```

2. Stop the ACM for Nitro Enclaves service.

   ```
   $ sudo systemctl stop nitro-enclaves-acm.service
   ```

3. Uninstall ACM for Nitro Enclaves.

```
$ sudo yum remove aws-nitro-enclaves-acm
```

Security

Cloud security at AWS is the highest priority. As an AWS customer, you benefit from a data center and network architecture that are built to meet the requirements of the most security-sensitive organizations.

Topics

- Shared responsibility
- Amazon EC2 security
- Enclave security
- Logging API calls for the Nitro Enclaves with AWS CloudTrail

Shared responsibility

Security is a shared responsibility between AWS and you. The shared responsibility model describes this as security of the cloud and security in the cloud:

- **Security of the cloud** – AWS is responsible for protecting the infrastructure that runs AWS services in the AWS Cloud. AWS also provides you with services that you can use securely. Third-party auditors regularly test and verify the effectiveness of our security as part of the AWS Compliance Programs. To learn about the compliance programs that apply to Amazon EC2, see AWS Services in Scope by Compliance Program.
- **Security in the cloud** – Your responsibility is determined by the AWS service that you use. You are also responsible for other factors including the sensitivity of your data, your company's requirements, and applicable laws and regulations.

Amazon EC2 security

The AWS Nitro Enclaves parent instance benefits from the standard security features and capabilities of Amazon EC2. The following documentation helps you understand how to apply the shared responsibility model when using Amazon EC2. It shows you how to configure Amazon EC2 to meet your security and compliance objectives. You also learn how to use other AWS services that help you to monitor and secure your Amazon EC2 resources.

- Infrastructure security in Amazon EC2

- Amazon EC2 and interface VPC endpoints
- Resilience in Amazon EC2
- Data protection in Amazon EC2
- Identity and access management for Amazon EC2
- Amazon EC2 key pairs and Linux instances
- Amazon EC2 security groups for Linux instances
- Update management in Amazon EC2
- Compliance validation for Amazon EC2

Enclave security

Nitro Enclaves use the same Nitro Hypervisor technology that provides CPU and memory isolation for Amazon EC2 instances in order to isolate the vCPUs and memory for an enclave from a parent instance. Enclaves provide only secure local socket connectivity with their parent instance. They have no persistent storage, SSH access, or external networking. Users cannot SSH into an enclave, and the data and applications inside the enclave cannot be accessed by the processes, applications, or users (root or admin) of the parent instance.

Nitro Enclaves also supports a cryptographic attestation feature, which allows you to verify an enclave's identity and ensure that only authorized code is running inside it. Attestation ensures that only authorized enclaves are able to decrypt sensitive data and perform specific cryptographic operations.

Nitro Enclaves integrates with AWS Key Management Service (KMS). AWS KMS makes it easy for you to create and manage cryptographic keys and control their use across a wide range of AWS services and in your applications. AWS KMS provides built-in attestation support that allows you to create condition keys for AWS KMS key policies that include an enclave's platform configuration registers. This ensures that only authorized enclaves are able to perform cryptographic operations using a specific KMS key.

Logging API calls for the Nitro Enclaves with AWS CloudTrail

AWS Nitro Enclaves is integrated with AWS CloudTrail, a service that provides a record of actions taken by a user or role in Nitro Enclaves. CloudTrail captures AWS KMS API calls made from enclaves as events. If you create a trail, you can enable continuous delivery of the events to an

Amazon Simple Storage Service (Amazon S3) bucket. If you don't configure a trail, you can still view the most recent events in the CloudTrail console in **Event history**. You can use the information collected by CloudTrail to audit AWS KMS API calls made by enclaves.

For more information about CloudTrail, see the AWS CloudTrail User Guide.

Nitro Enclaves information in CloudTrail

CloudTrail is enabled on your AWS account when you create the account. When supported event activity occurs in an enclave, that activity is recorded in a CloudTrail event along with other AWS service events in **Event history**. You can view, search, and download recent events in your AWS account. For more information, see Viewing Events with CloudTrail Event History.

For an ongoing record of events in your enclave, create a trail. A *trail* enables CloudTrail to deliver log files to an S3 bucket. By default, when you create a trail in the console, the trail applies to all AWS Regions. The trail logs events from all Regions in the AWS partition and delivers the log files to the S3 bucket that you specify. Additionally, you can configure other AWS services to further analyze and act upon the event data collected in CloudTrail logs. For more information, see the following:

- Overview for Creating a Trail
- Configuring Amazon SNS Notifications for CloudTrail

Nitro Enclaves supports logging the following Nitro Enclaves SDKs (that call AWS KMS APIs) as events in CloudTrail log files:

- kms-decrypt (Decrypt)
- generate-data-key (GenerateDataKey)
- generate-random (GenerateRandom)

Every event or log entry contains information about the origins of the request. Event logs generated by API calls from an enclave include the following additional fields that provide information about the identity of the enclave.

```
"additionalEventData": {
    "recipient": {
        "attestationDocumentModuleId": "enclave_id",
```

```
        "attestationDocumentEnclaveImageDigest": "PCR0"
    }
}
```

Example

```
"additionalEventData": {
    "recipient": {
        "attestationDocumentModuleId": "i-abc12345def67890a-enc9876abcd543210ef12",
        "attestationDocumentEnclaveImageDigest":
 "7fb5c55bc2ecbb68ed99a13d7122abfc0666b926a79d5379bc58b9445c84217f59cfdd36c08b2c79552928702efe2

    }
}
```

Understanding Nitro Enclaves log file entries

CloudTrail log files contain one or more log entries. An event represents a single request from any source and includes information about the requested action, the date and time of the action, request parameters, and so on. CloudTrail log files aren't an ordered stack trace of the public API calls, so they don't appear in any specific order. The following examples show CloudTrail log entries for the supported actions.

- GenerateRandom

```
{
     "eventVersion": "1.02",
     "userIdentity": {
         "type": "IAMUser",
         "principalId": "EX_PRINCIPAL_ID",
         "arn": "arn:aws:iam::111122223333:user/Alice",
         "accountId": "111122223333",
         "accessKeyId": "EXAMPLE_KEY_ID",
         "userName": "Alice"
     },
     "eventTime": "2014-11-04T00:52:37Z",
     "eventSource": "kms.amazonaws.com",
     "eventName": "GenerateRandom",
     "awsRegion": "us-east-1",
     "sourceIPAddress": "192.0.2.0",
     "userAgent": "AWS Internal",
     "requestParameters": null,
```

```
     "responseElements": null,
     "additionalEventData": {
         "recipient": {
             "attestationDocumentModuleId": "i-123456789abcde123-
enc123456789abcde12",
             "attestationDocumentEnclaveImageDigest":
 "ee0d451a2ff9aaaa9bccd07700b9cab123a0ac2386ef7e88ad5ea6c72ebabea840957328e2ec890b408c9b06cb8
         }
     },
     "requestID": "df1e3de6-63bc-11e4-bc2b-4198b6150d5c",
     "eventID": "239cb9f7-ae05-4c94-9221-6ea30eef0442",
     "readOnly": true,
     "resources": [],
     "eventType": "AwsApiCall",
     "recipientAccountId": "111122223333"
 }
```

- GenerateDataKey

```
{
     "eventVersion": "1.02",
     "userIdentity": {
         "type": "IAMUser",
         "principalId": "EX_PRINCIPAL_ID",
         "arn": "arn:aws:iam::111122223333:user/Alice",
         "accountId": "111122223333",
         "accessKeyId": "EXAMPLE_KEY_ID",
         "userName": "Alice"
     },
     "eventTime": "2014-11-04T00:52:40Z",
     "eventSource": "kms.amazonaws.com",
     "eventName": "GenerateDataKey",
     "awsRegion": "us-east-1",
     "sourceIPAddress": "192.0.2.0",
     "userAgent": "AWS Internal",
     "requestParameters": {
         "keyId": "1234abcd-12ab-34cd-56ef-1234567890ab",
         "numberOfBytes": 32
     },
     "responseElements": null,
     "additionalEventData": {
         "recipient": {
             "attestationDocumentModuleId": "i-123456789abcde123-
enc123456789abcde12",
```

```
            "attestationDocumentEnclaveImageDigest":
 "ee0d451a2ff9aaaa9bccd07700b9cab123a0ac2386ef7e88ad5ea6c72ebabea840957328e2ec890b408c9b06cb8

        }
    },
    "requestID": "e0eb83e3-63bc-11e4-bc2b-4198b6150d5c",
    "eventID": "a9dea4f9-8395-46c0-942c-f509c02c2b71",
    "readOnly": true,
    "resources": [{
        "ARN": "arn:aws:kms:us-
west-2:111122223333:key/1234abcd-12ab-34cd-56ef-1234567890ab",
        "accountId": "111122223333"
    }],
    "eventType": "AwsApiCall",
    "recipientAccountId": "111122223333"
 }
```

- Decrypt

```
{
    "eventVersion": "1.05",
    "userIdentity": {
        "type": "IAMUser",
        "principalId": "EX_PRINCIPAL_ID",
        "arn": "arn:aws:iam::111122223333:user/Alice",
        "accountId": "111122223333",
        "accessKeyId": "EXAMPLE_KEY_ID",
        "userName": "Alice"
    },
    "eventTime": "2020-07-27T22:58:24Z",
    "eventSource": "kms.amazonaws.com",
    "eventName": "Decrypt",
    "awsRegion": "us-west-2",
    "sourceIPAddress": "192.0.2.0",
    "userAgent": "AWS Internal",
    "requestParameters": {
        "encryptionAlgorithm": "SYMMETRIC_DEFAULT",
        "keyId": "12345ac3-fbbf-4143-abcd-28b39example"
    },
    "responseElements": null,
    "additionalEventData": {
        "recipient": {
            "attestationDocumentModuleId": "i-123456789abcde123-
enc123456789abcde12",
```

```
            "attestationDocumentEnclaveImageDigest":
 "ee0d451a2ff9aaaa9bccd07700b9cab123a0ac2386ef7e88ad5ea6c72ebabea840957328e2ec890b408c9b06cb8
        }
    },
    "requestID": "b4a65126-30d5-4b28-98b9-9153da559963",
    "eventID": "e5a2f202-ba1a-467c-b4ba-f729d45ae521",
    "readOnly": true,
    "resources": [
        {
            "accountId": "111122223333",
            "type": "AWS::KMS::Key",
            "ARN": "arn:aws:kms:us-east-2:111122223333:key/12345ac3-fbbf-4143-
abcd-28b39example"
        }
    ],
    "eventType": "AwsApiCall",
    "recipientAccountId": "111122223333"
 }
```

Nitro Enclaves Command Line Interface

The Nitro Enclaves CLI (Nitro CLI) is a command line tool for managing the lifecycle of enclaves. You can use the Nitro CLI to create, manage, and terminate enclaves. The Nitro CLI must be installed on the Amazon EC2 parent instance.

Contents

- Install the Nitro Enclaves CLI on Linux
- Install the Nitro Enclaves CLI on Windows
- Uninstall the Nitro Enclaves CLI on Linux
- Uninstall the Nitro Enclaves CLI on Windows
- Nitro Enclaves Command Line Interface reference
- Nitro Enclaves CLI error codes

Install the Nitro Enclaves CLI on Linux

The following instructions are for installing or uninstalling the AWS Nitro Enclaves CLI on or from a parent instance running Amazon Linux 2023 or Amazon Linux 2. For instructions for installing the Nitro CLI on different Linux distributions, see the Nitro CLI github repository.

Amazon Linux 2023

To install the Nitro CLI on an instance running AL2023

1. Install the Nitro CLI.

```
$ sudo dnf install aws-nitro-enclaves-cli -y
```

2. Install the Nitro Enclaves development tools needed to build enclave images. The development tools also includes some sample applications.

```
$ sudo dnf install aws-nitro-enclaves-cli-devel -y
```

3. Add your user to the ne user group.

```
$ sudo usermod -aG ne username
```

4. Add your user to the `docker` user group.

```
$ sudo usermod -aG docker username
```

> **Important**
>
> For the permissions changes to take effect, log out of the instance and then reconnect to it.

5. Verify that the Nitro CLI installed correctly.

```
$ nitro-cli --version
```

The command should return version information about the Nitro CLI.

6. Preallocate the memory and the vCPUs that you intend to use for the enclaves.

> **Important**
>
> Nitro Enclaves uses an allocator service to preallocate vCPUs and memory to the enclaves. The amount of vCPUs and memory to preallocate are defined in the allocator service configuration file (`/etc/nitro_enclaves/allocator.yaml`). By default, the configuration file is set up to preallocate 512 MiB of memory and 2 vCPUs for use by the enclaves. In some cases, you might need to manually update the configuration file to preallocate a different number vCPUs or amount of memory. For example:
>
> - If you launched an AWS Graviton-based instance with 2 vCPUs, you must configure the allocate service to preallocate only 1 vCPU.
> - If you launched an instance with 4 or more vCPUs, you can configure the allocator service to preallocate more vCPUs to the enclave.
> - If you are going to run multiple enclaves, you must configure the allocator service to preallocate enough vCPUs and memory for all of the enclaves. For example, to run 3 enclaves with 4 vCPUs and 2 GiB memory each, you must configure the allocator service to preallocate 12 vCPUs and 6 GiB of memory.

If you need to change the configuration file, use your preferred text editor to open `/etc/nitro_enclaves/allocator.yaml`. Then, for `memory_mib` and `cpu_count`, specify the overall amount of memory (in MiB) and the number of vCPUs that you want to preallocate. Save and close the file and then run the command below.
If you want to preallocate the default 512 MiB of memory and 2 vCPUs, you do not need to make any changes to the configuration file.

Run the following command to allocate the resource specified in the configuration file and to ensure that they are automatically allocated every time the instance starts.

```
$ sudo systemctl enable --now nitro-enclaves-allocator.service
```

Note

When you create an enclave, the requested memory and vCPUs must be less than or equal to the values that you specified here. If you need to create an enclave with more memory or vCPUs in the future, you must update the values in this file and restart the service.

7. Start the Docker service and ensure that it starts every time the instance starts.

```
$ sudo systemctl enable --now docker
```

Amazon Linux 2

To install the Nitro CLI on an instance running AL2

1. Install the Nitro CLI.

```
$ sudo amazon-linux-extras install aws-nitro-enclaves-cli -y
```

2. Install the Nitro Enclaves development tools needed to build enclave images. The development tools also includes some sample applications.

```
$ sudo yum install aws-nitro-enclaves-cli-devel -y
```

3. Add your user to the ne user group.

```
$ sudo usermod -aG ne username
```

4. Add your user to the `docker` user group.

```
$ sudo usermod -aG docker username
```

> **Important**
>
> For the permissions changes to take effect, log out of the instance and then reconnect to it.

5. Verify that the Nitro CLI installed correctly.

```
$ nitro-cli --version
```

The command should return version information about the Nitro CLI.

6. Preallocate the memory and the vCPUs that you intend to use for the enclaves.

> **Important**
>
> Nitro Enclaves uses an allocator service to preallocate vCPUs and memory to the enclaves. The amount of vCPUs and memory to preallocate are defined in the allocator service configuration file (`/etc/nitro_enclaves/allocator.yaml`). By default, the configuration file is set up to preallocate 512 MiB of memory and 2 vCPUs for use by the enclaves. In some cases, you might need to manually update the configuration file to preallocate a different number vCPUs or amount of memory. For example:
>
> - If you launched an AWS Graviton-based instance with 2 vCPUs, you must configure the allocate service to preallocate only 1 vCPU.
> - If you launched an instance with 4 or more vCPUs, you can configure the allocator service to preallocate more vCPUs to the enclave.

- If you are going to run multiple enclaves, you must configure the allocator service to preallocate enough vCPUs and memory for all of the enclaves. For example, to run 3 enclaves with 4 vCPUs and 2 GiB memory each, you must configure the allocator service to preallocate 12 vCPUs and 6 GiB of memory.

If you need to change the configuration file, use your preferred text editor to open `/etc/nitro_enclaves/allocator.yaml`. Then, for `memory_mib` and `cpu_count`, specify the overall amount of memory (in MiB) and the number of vCPUs that you want to preallocate. Save and close the file and then run the command below.
If you want to preallocate the default 512 MiB of memory and 2 vCPUs, you do not need to make any changes to the configuration file.

Run the following command to allocate the resource specified in the configuration file and to ensure that they are automatically allocated every time the instance starts.

```
$ sudo systemctl enable --now nitro-enclaves-allocator.service
```

Note

When you create an enclave, the requested memory and vCPUs must be less than or equal to the values that you specified here. If you need to create an enclave with more memory or vCPUs in the future, you must update the values in this file and restart the service.

7. Start the Docker service and ensure that it starts every time the instance starts.

```
$ sudo systemctl enable --now docker
```

Install the Nitro Enclaves CLI on Windows

The AWS Nitro Enclaves CLI is packaged together with all of the components that are required to run Nitro Enclaves on a Windows parent instance. The package includes kernel drivers for the

Enclave and vsock devices, a service provider interface for Winsock to support vsock sockets, the vsock-proxy, and the AWS Nitro Enclaves CLI.

The following instructions are for installing and uninstalling the AWS Nitro Enclaves CLI on or from a parent instance running Windows.

> **Note**
>
> You may get the following error when you install, uninstall, or update the Nitro CLI: `Installation failed with code 3010`. This message indicates that a reboot is required to complete the installation. This error is likely caused by a component in use, such as a running enclave or a vsock-proxy process. To complete the installation, shut down all applications running on the instance and reboot it.

Install Nitro CLI

To use the Nitro Enclaves on your parent instance, you must install the **AWSNitroEnclavesWindows** package using AWS Systems Manager Distributor.

Before you can install a package using the AWS Systems Manager Distributor, you must first complete the Distributor prerequisites.

After you have completed the prerequisites, install the **AWSNitroEnclavesWindows** package. For more information, see one of the following in the *AWS Systems Manager User Guide*:

- Installing or updating a package one time using the console
- Installing a package one time using the AWS CLI

You must reload the path environment variable from the updated environment in any PowerShell or command prompt already open on the instance. When you open a new PowerShell or command prompt, Windows automatically updates the path variable.

Uninstall the Nitro Enclaves CLI on Linux

If you no longer want to use AWS Nitro Enclaves on your Linux instance, use the following command to uninstall the AWS Nitro Enclaves CLI.

Amazon Linux 2023

```
$ sudo dnf remove aws-nitro-enclaves-cli
```

Amazon Linux 2

```
$ sudo yum remove aws-nitro-enclaves-cli
```

Uninstall the Nitro Enclaves CLI on Windows

If you no longer want to use AWS Nitro Enclaves on your Windows instance, you can remove the AWS Nitro Enclaves CLI from the parent instance by uninstalling the **AWSNitroEnclavesWindows** package using the AWS Systems Manager Distributor. For more information see Uninstall a package in the *AWS Systems Manager User Guide*.

Alternatively, you can uninstall the AWS Nitro Enclaves CLI using **Programs and Features**, which can be accessed using the Windows Control Panel.

Nitro Enclaves Command Line Interface reference

The following commands are available in the Nitro CLI. All of the Nitro CLI commands start with `nitro-cli`, followed by one of the following subcommands. To view the command line help for a command, add the `--help` option.

Commands

- nitro-cli build-enclave
- nitro-cli run-enclave
- nitro-cli describe-enclaves
- nitro-cli console
- nitro-cli describe-eif
- nitro-cli sign-eif
- nitro-cli pcr
- nitro-cli terminate-enclave

nitro-cli build-enclave

Converts a Docker image into an enclave image file (`.eif`). You can specify either a local directory containing a Dockerfile, or a Docker image in a Docker repository.

> **Important**
>
> This command is not supported on Windows. If you are using a Windows parent instance, you must run this command on a Linux computer and then transfer the enclave image file (`.eif`) to the Windows parent instance.
>
> You can build enclave images files using the Nitro CLI on any Linux environment, including outside of AWS. To manage the lifecycle of an instance—such as with the `run-enclave` command—you will need to use the Nitro CLI on a parent instance (EC2 instance with Nitro Enclave enabled).

The command returns a set of measurements (SHA384 hashes) that are unique to the enclave image file. These measurements are provided in the form of platform configuration registers (PCRs). The PCRs are used during the enclave's attestation process. For more information, see Nitro Enclaves concepts.

For example, when using Nitro Enclaves with AWS Key Management Service (AWS KMS), you can specify these PCRs in condition keys for customer managed keys policies. When an application in the enclave performs an AWS KMS operation, AWS KMS compares the PCRs in the enclave's signed attestation document with the PCRs specified in the condition keys of the KMS key policy before allowing the operation.

Syntax

```
nitro-cli build-enclave
    --docker-uri repository:tag
    [--docker-dir /path_to/dockerfile_directory ]
    --output-file file-location
    [--private-key key]
    --signing-certificate certificate.pem
    [--name image_name]
    [--version image_version]
```

Options

`--docker-uri`

The uniform resource identifier (URI) of a Docker image in a Docker repository. The URI is specified using the `repository:tag` format.

Type: String

Required: Yes

`--docker-dir`

The path to a local directory containing a Dockerfile.

Type: String

Required: No

`--output-file`

The file name of the enclave image file that is created.

Type: String

Required: Yes

`--private-key`

The private key to use to sign the enclave image file. This can be a KMS key ARN, or a path to a local private key file. For more information, see Key ARN.

Only ECDSA keys are supported for code for signing. If you specify `--private-key` then you must also specify `--signing-certificate`. If you specify this parameter, the command creates a signed enclave image file. The command output will include an additional PCR, PCR8, which can be used in condition keys for KMS key policies. For more information, see Where to get an enclave's measurements.

Type: String

Required: No

`--signing-certificate`

The signing key to use to sign the enclave image file. If you specify `--signing-certificate` then you must also specify `--private-key`. If you specify these parameters, the command

creates a signed enclave image file. The command output will include and additional PCR, PCR8, which can be used in condition keys for KMS key policies. For more information, see Where to get an enclave's measurements.

> **Important**
>
> Ensure that the specified certificate is still valid. If you attempt to start an enclave with an enclave image file that is signed with a certificate that is no longer valid, the `nitro-cli run-enclave` fails with errors E36, E39, and E11.

Type: String

Required: No

Output

`Measurements`

The cryptographic measurements (SHA384 hashes) that are unique to the enclave image file.

Type: String

Example

The following example converts a Docker image with a URI of `sample:latest` to an enclave image file named `sample.eif`.

Command

```
nitro-cli build-enclave --docker-uri sample:latest --output-file sample.eif
```

Output

```
Enclave Image successfully created.
{
  "Measurements": {
    "HashAlgorithm": "Sha384 { ... }",
```

```
    "PCR0":
 "EXAMPLE59044e337c00068c2c033546641e37aa466b853ca486dd149f641f15071961db2a0827beccea9cade3EXAM
    "PCR1":
 "EXAMPLE7783d0c23167299fbe5a69622490a9bdf82e94a0a1a48b0e7c56130c0c1e6555de7c0aa3d7901fbc58EXAM
    "PCR2":
 "EXAMPLE4b51589e8374b7f695b4649d1f1e9b528b05ab75a49f9a0a4a1ec36be81280caab0486f660b9207ac0EXAM
  }
}
```

The following example converts a Docker image with a URI of `sample:latest` to an enclave image file named `sample.eif`, and signs it using a KMS key.

Command

```
nitro-cli build-enclave --docker-uri sample:latest --output-file sample.eif --private-
key arn:aws:kms:eu-west-1:123456789321:key/abcdef12-3456-789a-bcde-111122223333 --
signing-certificate certificate.pem
```

Output

```
Enclave Image successfully created.{
"Measurements": {
"HashAlgorithm": "Sha384 { ... }",
    "PCR0":
 "EXAMPLE59044e337c00068c2c033546641e37aa466b853ca486dd149f641f15071961db2a0827beccea9cade3EXAM
    "PCR1":
 "EXAMPLE7783d0c23167299fbe5a69622490a9bdf82e94a0a1a48b0e7c56130c0c1e6555de7c0aa3d7901fbc58EXAM
    "PCR2":
 "EXAMPLE4b51589e8374b7f695b4649d1f1e9b528b05ab75a49f9a0a4a1ec36be81280caab0486f660b9207ac0EXAM
    "PCR8":
 "EXAMPLEdcca7f74398ae152d6ee245d8ac2cd430fb63644b46bf47b7d36b53b91c7597edda2d5df772cc81b72EXAM
  }
}
```

nitro-cli run-enclave

Launches a new enclave. This command partitions the specified number of vCPUs and the amount of memory from the Amazon EC2 parent instance to create the enclave. You also need to provide an enclave image file (`.eif`) that contains the operating system and the applications that you want to run inside the enclave.

> **Important**
>
> If you attempt to start an enclave with an enclave image file that is signed with a certificate that is no longer valid, the `nitro-cli run-enclave` command fails with errors E36, E39, and E11.

Syntax

```
nitro-cli run-enclave
    [--enclave-name enclave_name]
    [--cpu-count number_of_vcpus
    --cpu-ids list_of_vcpu_ids]
    --memory amount_of_memory_in_MiB
    --eif-path path_to_enclave_image_file
    [--enclave-cid cid_number]
    [--debug-mode]
    [--attach-console]
```

Alternatively, pass the enclave settings using a JSON file as follows.

```
nitro-cli run-enclave --config config_file.json
```

The following is an example JSON file.

```
{
    "enclave_name": enclave_name,
    "cpu_count": number_of_vcpus,
    "cpu_ids": list_of_vcpu_ids,
    "memory_mib": amount_of_memory_in_MiB,
    "eif_path": "path_to_enclave_image_file",
    "enclave_cid": cid_number,
    "debug_mode": true|false,
    "attach_console": true|false
}
```

Options

`--enclave-name`

A unique name for the enclave. You can use this name to reference the enclave when using the `nitro-cli console` and `nitro-cli terminate-enclave` commands.

If you do not specify a name, the name of the enclave image file (.eif) is used as the enclave name.

Type: String

Required: No

`--cpu-count`

The number of vCPUs to allocate to the enclave.

> **Note**
>
> - Amazon EC2 instances support multithreading, which enables multiple threads to run concurrently on a single CPU core. Each thread is represented as a virtual CPU (vCPU) on the instance. For more information about vCPUs, see Optimize CPU options in the *Amazon EC2 User Guide*.
> - If the parent instance is enabled for multithreading, you must specify an even number of vCPUs.

The number of vCPUs that you can allocate to an enclave depends on the size and configuration of the parent instance. If the parent instance is enabled for multithreading, you must leave at least 2 vCPUs for the parent instance. If multithreading is not enabled, you must leave at least 1 vCPU for the parent instance. For example, if your parent instance has 4 vCPUs and it is enabled for multithreading, you can allocate up to 2 vCPUs to the enclave.

You must specify either `--cpu-count` or `--cpu-ids`. If you specify this option, omit `--cpu-ids`.

Type: Integer

Required: Conditional

`--cpu-ids`

The IDs of the vCPUs to allocate to the enclave.

> **Note**
>
> - Amazon EC2 instances support multithreading, which enables multiple threads to run concurrently on a single CPU core. Each thread is represented as a virtual CPU (vCPU) on the instance. For more information about vCPUs, see Optimize CPU options in the *Amazon EC2 User Guide*.
> - If the parent instance is enabled for multithreading, you must specify an even number of vCPUs.

The number of vCPUs that you can allocate to an enclave depends on the size and configuration of the parent instance. If the parent instance is enabled for multithreading, you must leave at least 2 vCPUs for the parent instance. If multithreading is not enabled, you must leave at least 1 vCPU for the parent instance. For example, if your parent instance has 4 vCPUs and it is enabled for multithreading, you can allocate up to 2 vCPUs to the enclave.

You must specify either `--cpu-count` or `--cpu-ids`. If you specify this option, omit `--cpu-count`.

Type: String

Required: Conditional

`--memory`

The amount of memory (in MiB) to allocate to the enclave.

The amount of memory that you can allocate to an enclave depends on the size of the parent instance and the applications that you intend to run on it. The specified amount of memory cannot exceed the amount of memory provided by the parent instance. You must leave enough memory for the applications running on the parent instance. You must allocate a minimum of 64 MiB of memory to the enclave.

Type: Integer (MiB)

Required: Yes

`--eif-path`

The path to the enclave image file.

Type: String

Required: Yes

`--enclave-cid`

The context identifier (CID) for the enclave. The CID is the socket address used by the *vsock* socket. Only CIDs of 4 and higher can be specified. If you omit this option, a random CID is allocated to the enclave.

Type: Integer

Required: No

`--debug-mode`

Indicates whether to run the enclave in debug mode. Specify this option to enable debug mode, or omit it to disable debug mode.

If you enable debug mode, you can view the enclave's console in read-only mode using the `nitro-cli console` command. Enclaves booted in debug mode generate attestation documents with PCRs that are made up entirely of zeros.

Required: No

`--attach-console`

Attach the enclave console immediately after starting the enclave.

`--config`

The path to a .json configuration file that specifies the parameters for the enclave. If you specify `--config`, the specified JSON file must include the required and optional parameters as described above, and you must not specify any other parameters in the command itself.

Type: String

Required: No

Output

`EnclaveName`

The unique name of the enclave.

Type: String

`EnclaveID`

The unique ID of the enclave.

Type: String

`ProcessID`

The process identifier (PID) of the process holding the enclave's resources.

Type: String

`EnclaveCID`

The context ID (CID) of the enclave.

Type: Integer

`NumberOfCPUs`

The number of vCPUs allocated to the enclave from the parent instance.

Type: Integer

`CPUIDs`

The IDs of the vCPUs allocated to the enclave from the parent instance.

Type: String

`MemoryMiB`

The amount of memory (in MiB) allocated to the enclave from the parent instance.

Type: Integer

Examples

Example 1: Inline parameters

The following example creates an enclave with 2 vCPUs, 1600 MiB of memory, and a context ID of 10. It also uses an enclave image file named `sample.eif`, which is located in the same directory from which the command is being run.

Command

```
nitro-cli run-enclave --enclave-name my-enclave --cpu-count 2 --memory 1600 --eif-
path sample.eif --enclave-cid 10
```

Output

```
Start allocating memory...
Started enclave with enclave-cid: 10, memory: 1600 MiB, cpu-ids: [1, 3]
{
    "EnclaveName": "my_enclave",
    "EnclaveID": "i-abc12345def67890a-enc9876abcd543210ef12",
    "ProcessID": 12345,
    "EnclaveCID": 10,
    "NumberOfCPUs": 2,
    "CPUIDs": [
        1,
        3
    ],
    "MemoryMiB": 1600
}
```

Example 2: Config file

The following example creates an enclave with 2 vCPUs, 1600 MiB of memory, and a context ID of 10. It also uses an enclave image file named `sample.eif`, which is located in the same directory from which the command is being run.

Command

```
nitro-cli run-enclave --config enclave_config.json
```

The following is an example of the `enclave_config.json` file.

```
{
    "enclave_name": "my_enclave",
    "cpu_count": 2,
    "memory_mib": 1600,
    "eif_path": "sample.eif",
    "enclave_cid": 10,
    "debug_mode": true
}
```

Output

```
Start allocating memory...
Started enclave with enclave-cid: 10, memory: 1600 MiB, cpu-ids: [1, 3]
{
    "EnclaveName": "my_enclave",
    "EnclaveID": "i-abc12345def67890a-enc9876abcd543210ef12",
    "ProcessID": 12345,
    "EnclaveCID": 10,
    "NumberOfCPUs": 2,
    "CPUIDs": [
        1,
        3
    ],
    "MemoryMiB": 1600
}
```

nitro-cli describe-enclaves

Describes an enclave.

Syntax

```
nitro-cli describe-enclaves
```

Options

This command has no options.

Output

`EnclaveName`

The unique name of the enclave.

Type: String

`EnclaveID`

The unique ID of the enclave.

Type: String

`ProcessID`

[Linux parent instances only] The process identifier (PID) of the process holding the enclave's resources.

Type: String

`EnclaveCID`

The unique context ID (CID) of the enclave. The CID is the socket address used by the *vsock* socket.

Type: Integer

`NumberOfCPUs`

The number of vCPUs allocated to the enclave from the parent instance.

Type: Integer

`CPUIDs`

[Linux parent instances only] The IDs of the vCPUs allocated to the enclave from the parent instance.

Type: Integer

`MemoryMiB`

The amount of memory (in MiB) allocated to the enclave from the parent instance.

Type: Integer

State

The current status of the enclave.

Possible values: `running` | `terminating`

Type: String

Flags

Indicates if the enclave is in debug mode. None indicates that debug mode is disabled. Debug indicates that debug mode is enabled.

Possible values: None | Debug

Type: String

Example

The following example describes an enclave.

Command

```
nitro-cli describe-enclaves
```

Output

```
[
    {
        "EnclaveName": "my_enclave",
        "EnclaveID": "i-abc12345def67890a-enc9876abcd543210ef12",
        "ProcessID": 12345,
        "EnclaveCID": 10,
        "NumberOfCPUs": 2,
        "CPUIDs": [
            1,
            3
        ],
        "MemoryMiB": 1600,
```

```
        "State": "RUNNING",
        "Flags": "NONE"
    }
]
```

nitro-cli console

Enters a read-only console for the specified enclave. This enables you to view the enclave's console output to assist with troubleshooting. You can use this command only on an enclave that was launched with the `--debug-mode` option.

Syntax

```
nitro-cli console
    [--enclave-name enclave_name]
    [--enclave-id enclave_id]
    [--disconnect-timeout number_of_seconds]
```

Options

`--enclave-name`

The unique name of the enclave. You must specify either `--enclave-name` or `--enclave-id`.

Type: String

Required: Conditional

`--enclave-id`

The unique ID of the enclave. You must specify either `--enclave-id` or `--enclave-name`.

Type: String

Required: Conditional

`--disconnect-timeout`

The number of seconds after which to automatically disconnect idle console sessions.

Type: Integer

Required: No

Example

The following command enters a read-only console for an enclave with an ID of `i-05f6ed443ae428c95-enc173dfe3e2b1c87b`. The session automatically disconnects if the connection is idle for `60` seconds.

Command

```
nitro-cli console --enclave-id i-05f6ed443ae428c95-enc173dfe3e2b1c87b --disconnect-
timeout 60
```

nitro-cli describe-eif

Describes the specified enclave image file (`.eif`). The output is a static description of the enclave image file that includes the enclave image file version, build measurements, signing certificate information, the result of the CRC and signature check, and the metadata added at build time.

Syntax

```
nitro-cli describe-eif
    --eif-path path_to_enclave_image_file
```

Options

`--eif-path`

The path to the enclave image file.

Type: String

Required: Yes

Output

`Measurements`

The cryptographic measurements (SHA384 hashes) that are unique to the enclave image file.

Type: String

Example

The following example describes an enclave image file named `sample.eif`.

Command

```
nitro-cli describe-eif --eif-path image.eif
```

Output

```
{
  "Measurements": {
    "HashAlgorithm": "Sha384 { ... }",
    "PCR0":
 "EXAMPLE59044e337c00068c2c033546641e37aa466b853ca486dd149f641f15071961db2a0827beccea9cade3EXAM
    "PCR1":
 "EXAMPLE7783d0c23167299fbe5a69622490a9bdf82e94a0a1a48b0e7c56130c0c1e6555de7c0aa3d7901fbc58EXAM
    "PCR2":
 "EXAMPLE4b51589e8374b7f695b4649d1f1e9b528b05ab75a49f9a0a4a1ec36be81280caab0486f660b9207ac0EXAM
  }
}
```

nitro-cli sign-eif

Signs an existing enclave image file (`.eif`). You must specify a private key and a signing certificate. For the private key, you can use a KMS key ARN or a local private key file.

The signature is added to the enclave image file (`.eif`). The signature is updated if it already exists in the enclave image file.

The command returns a set of measurements (SHA384 hashes) that are unique to the enclave image file. These measurements are provided in the form of platform configuration registers (PCRs). The PCRs are used during the enclave's attestation process. For more information, see Nitro Enclaves concepts.

For example, when using Nitro Enclaves with AWS Key Management Service (AWS KMS), you can specify these PCRs in condition keys for customer managed keys policies. When an application in the enclave performs an AWS KMS operation, AWS KMS compares the PCRs in the enclave's signed

attestation document with the PCRs specified in the condition keys of the KMS key policy before allowing the operation.

Syntax

```
nitro-cli sign-eif
    --eif-path /path/to/eif
    --private-key key
    --signing-certificate certificate.pem
```

Options

`--eif-path`

The path to the enclave image file.

Type: String

Required: Yes

`--private-key`

The private key to use to sign the enclave image file. This can be a KMS key ARN, or a path to a local private key file. Only ECDSA keys are supported for signing.

Type: String

Required: Yes

`--signing-certificate`

The signing key to use to sign the enclave image file.

Type: String

Required: Yes

> **Important**
>
> Ensure that the specified certificate is valid. If you start an enclave with an invalid certificate, then the `nitro-cli run-enclave` command fails with errors E36, E39, and E11. For more information, see Nitro Enclaves CLI error codes.

Output

`Measurements`

The cryptographic measurements (SHA384 hashes) that are unique to the enclave image file. The command output includes an additional PCR, PCR8 that can be used in condition keys for KMS key policies. For more information, see Where to get an enclave's measurements.

Type: String

Example

The following example signs the enclave image file `sample.eif` with the given KMS key.

Command

```
nitro-cli sign-eif --eif-path sample.eif --private-key arn:aws:kms:eu-
west-1:123456789321:key/abcdef12-3456-789a-bcde-111122223333 --signing-certificate
 certificate.pem
```

Output

```
Enclave Image successfully signed.{
"Measurements": {
"HashAlgorithm": "Sha384 { ... }",
    "PCR0":
 "EXAMPLE59044e337c00068c2c033546641e37aa466b853ca486dd149f641f15071961db2a0827beccea9cade3EXAM
    "PCR1":
 "EXAMPLE7783d0c23167299fbe5a69622490a9bdf82e94a0a1a48b0e7c56130c0c1e6555de7c0aa3d7901fbc58EXAM
    "PCR2":
 "EXAMPLE4b51589e8374b7f695b4649d1f1e9b528b05ab75a49f9a0a4a1ec36be81280caab0486f660b9207ac0EXAM
    "PCR8":
 "EXAMPLEdcca7f74398ae152d6ee245d8ac2cd430fb63644b46bf47b7d36b53b91c7597edda2d5df772cc81b72EXAM
  }
}
```

nitro-cli pcr

Returns the platform configuration register (PCR) value for a specified input file or PEM certificate. You can use this command to identify the files and signing certificate that were used to sign an enclave by comparing the command output with PCR values in the enclave's build measurements.

Syntax

```
nitro-cli pcr
    [--input path_to_file]
    [--signing-certificate path_to_certificate]
```

Options

`--input`

The path to the file for which to generate the platform configuration register (PCR) value.

You must specify either `--input` or `--signing-certificate`.

Type: String

Required: Conditional

`--signing-certificate`

The path to the PEM certificate for which to generate PCR8. This option is used to specifically request the PCR8 value by performing deserialisation of the certificate and PEM format validation.

You must specify either `--input` or `--signing-certificate`.

Type: String

Required: Conditional

Output

PCR

The platform configuration register (PCR) value for the specified input file or PEM certificate.

Type: String

Example

The following example generates the PCR8 value for a PEM certificate named `cert.pem`.

Command

```
nitro-cli pcr --signing-certificate cert.pem
```

Output

```
{
    "PCR8":
 "example39de75e8ed2939e95examplea96f2c79eaf5d5ac3bacf2cb76c75a31f9examplef55b29f0acd256b8examp
}
```

nitro-cli terminate-enclave

Terminates a specific enclave or all enclaves owned by the current user.

To terminate a specific enclave, specify `--enclave-name` or `--enclave-id`. To terminate all enclaves, specify `--all`.

Syntax

```
nitro-cli terminate-enclave
    [--enclave-id enclave_id]
    [--enclave-name enclave_name]
    [--all]
```

Options

`--enclave-name`

The unique name of the enclave to terminate. You must specify either `--enclave-name` or `--enclave-id`.

Type: String

Required: Conditional

`--enclave-id`

The unique ID of the enclave to terminate. You must specify either `--enclave-id` or `--enclave-name`.

Type: String

Required: Conditional

`--all`

Indicates whether to terminate all of the enclaves owned by the current user. If you specify this option, omit `--enclave-id` and `--enclave-name`.

Required: No

Example

Example: Terminate specific enclave

The following example terminates an enclave with an ID of `i-abc12345def67890a-enc9876abcd543210ef12`.

Command

```
nitro-cli terminate-enclave --enclave-id i-abc12345def67890a-enc9876abcd543210ef12
```

Output

```
Successfully terminated enclave i-abc12345def67890a-enc9876abcd543210ef12.
{
  "EnclaveID": "i-abc12345def67890a-enc9876abcd543210ef12",
  "Terminated": true
}
```

Example: Terminate all running enclaves

The following example terminates all of the enclaves owned by the current user.

Command

```
nitro-cli terminate-enclave --all
```

Output

```
Successfully terminated enclave i-abc12345def67890a-enc9876abcd543210ef12.
{
  "EnclaveID": "i-abc12345def67890a-enc9876abcd543210ef12",
```

```
  "Terminated": true
}
```

Nitro Enclaves CLI error codes

This section lists the possible errors that the Nitro CLI can return.

E01

Missing mandatory argument. At least one mandatory argument has not been specified. Ensure that all mandatory arguments have been specified.

E02

Conflicting arguments. The command includes two or more incompatible arguments. Ensure that you specify only one of the conflicting arguments. For example, you cannot specify `--cpu-count` and `--cpu-ids` in the same `run-enclave` command.

E03

Invalid argument provided. A value of the incorrect type has been specified for one or more arguments. For example, a string was specified for an argument that expects an integer. Ensure that all values are of the expected type.

E04

Socket pair creation failure. The Nitro CLI attempted to open a stream pair with the enclave, but the stream initialization has failed. Either there is insufficient memory available for the Nitro CLI process, or the system-wide maximum number of open descriptors was reached. Retry the command. If that fails, reboot the instance and then retry the command.

E05

Process spawn failure. The Nitro CLI failed to spawn the enclave process while running the `run-enclave` command. Either the system has reached its maximum number of threads, or there is insufficient memory available to spawn the new process. Ensure that the system has enough free memory and then retry the command. If that fails, reboot the instance and then retry the command.

E06

Daemonize process failure. An error occurred while attempting to daemonize the newly spawned enclave process. Possible reasons are that the system has reached its maximum

number of threads, there is insufficient memory available to spawn the new process, or the configuration of the Nitro CLI main process is not allowing the daemon creation process. Ensure that the system has enough free memory and then retry the command. If that fails, reboot the instance and then retry the command.

E07

Read from disk failure. The Nitro CLI failed to read content from the enclave's socket directory (typically `/var/run/nitro_enclaves/`) while running the `describe-enclave` command. Ensure that the directory exists and that it has the correct permissions. Alternatively, run the Nitro Enclaves configuration script to reconfigure the environment.

E08

Unusable connection error. The Nitro CLI is unable to connect to an enclave. Ensure that it exists and that it is in the `running` state.

E09

Socket close error. The Nitro CLI is unable to close the communication channel. The socket close operation was interrupted by another signal. Retry the command.

E10

Socket connect set timeout error. The Nitro CLI failed to configure a specific timeout for the specified socket. Ensure that the operation is being performed on a valid socket.

E11

Socket error. An unexpected error occurred with the socket.

E12

Epoll error. The Nitro CLI failed to register the enclave descriptor for event monitoring with `epoll`. Either the system has insufficient memory to handle the requested operation, or the per-user maximum number of watches was reached while trying to register a new descriptor on an epoll instance. Ensure that the system has enough free memory and then retry the command. If that fails, reboot the instance and then retry the command.

E13

Inotify error. The Nitro CLI failed to configure a socket for monitoring. Either the system has insufficient memory to handle the requested operation, or the user limit of inotify watches has been reached. Ensure that the system has enough free memory and then retry the command. If that fails, reboot the instance and then retry the command.

E14

Invalid command. An unknown command or command argument was specified. Verify the command and argument names.

E15

Lock acquire failure. The Nitro CLI failed to obtain a lock on an object with concurrent access, such as a structure containing information about a running enclave. A previous thread failed an operation while holding the lock. Retry the command. If that fails, reboot the instance and then retry the command.

E16

Thread join failure. The Nitro CLI failed to join a thread after it finished executing. Retry the command.

E17

Serde error. An error occurred while serializing or deserializing a command or command response. The JSON in the supplied command might not be valid. If you are supplying command arguments in the JSON file, ensure that the supplied JSON is valid.

E18

File permissions error. You do not have permission to modify the logging file (typically `/var/log/nitro_enclaves/nitro_enclaves.log`). Ensure that your user is part of the `ne` user group. For more information, see Install the Nitro Enclaves CLI on Linux.

E19

File operation failure. The system failed to perform the requested file operations. Ensure that the file on which the operation is performed exists and that you have permission to modify it.

E20

Invalid CPU configuration. The same CPU ID has been specified more than once for the `--cpu-ids` argument. Ensure that each vCPU ID is specified only once.

E21

No such CPU available in the pool. One or more of the specified CPU IDs does not exist in the CPU pool. Either retry the command and specify different vCPU IDs, or preallocate the environment resources so that the vCPU pool includes the vCPU IDs that you want to use. For more information, see Install the Nitro Enclaves CLI on Linux.

E22

Insufficient CPUs available in the pool. The number of requested vCPUs is greater than the number of available vCPUs. Either specify a number of vCPUs less than or equal to the configured vCPU pool size, or preallocate the environment resources so that the vCPU pool includes the number of vCPUs that you want to use. For more information, see Install the Nitro Enclaves CLI on Linux.

E23

Malformed CPU ID error. This error appears when a `lscpu` line is malformed and it reports an online CPUs list that is not valid. Ensure that the `lscpu` output is not corrupt.

E24

CPU error. A CPU line interval is not valid. Ensure that the `lscpu` output is not corrupt.

E25

No such hugepage flag error. The enclave process attempted to use a hugepage size that is not valid for initializing the enclave memory. Make sure that the Nitro CLI code has not been modified to include hugepage sizes that are not valid.

E26

Insufficient memory requested. Insufficient memory was requested for the enclave. The memory should be equal to or greater than the size of the enclave image file. Preallocate enough memory to ensure that the enclave image file fits in the enclave's memory. For more information, see Install the Nitro Enclaves CLI on Linux.

E27

Insufficient memory available. The amount of requested memory is greater than the amount of available memory. The enclave memory should not be greater than the size of the configured hugepage memory. For example, if you request 100 MiB of memory while the allocated hugepage memory is 80MiB, the request fails. Preallocate enough memory for the enclave. For more information, see Install the Nitro Enclaves CLI on Linux. Alternatively, specify a smaller amount of memory with the `run-enclave` command.

E28

Invalid enclave descriptor. `NE_CREATE_VM ioctl` returned an error. Review the error backtrace for more information.

E29

Ioctl failure. An unexpected `ioctl` error occurred. Review the error backtrace for more information.

E30

Ioctl image get load info failure. The `ioctl` used for getting the memory load information failed. Review the error backtrace for more information.

E31

Ioctl set memory region failure. The `ioctl` used for setting a given memory region has failed. Review the error backtrace for more information.

E32

Ioctl add vCPU failure. The `ioctl` used for adding a vCPU failed. Review the error backtrace for more information.

E33

Ioctl start enclave failure. The `ioctl` used for starting an enclave has failed. Review the error backtrace for more information.

E34

Memory overflow. An error occurred while loading the enclave image file in memory regions that will be conceded to the future enclave. For example, this can occur if the regions offset plus the enclave image file size exceeds the maximum address of the target platform.

E35

EIF file parsing error. Failed to fill a memory region with a section of the enclave image file.

E36

Enclave boot failure. The enclave failed to return a `ready` signal after booting. For example, if booting from an enclave image file that is not valid, the enclave process exits immediately, before returning a ready signal. Ensure that the enclave image file is not corrupt. Review the error backtrace for more information.

E37

Enclave event wait error. Failed to monitor an enclave descriptor for events.

E38

Enclave process command not executed error. At least one enclave process failed to provide the description information.

E39

Enclave process connection failure. The enclave manager failed to connect to at least one enclave process for retrieving the description information.

E40

Socket path not found. The Nitro CLI failed to build the corresponding socket path starting from a given enclave ID.

E41

Enclave process send reply failure. The enclave process failed to report its status to the requesting command.

E42

Enclave mmap error. Failed to allocate memory to the enclave. Make sure that the system has enough free memory available. Retry the command. If that fails, reboot the instance and then retry the command.

E43

Enclave munmap error. Failed to unmap an enclave's memory. Make sure that the Nitro CLI code has not been modified to pass flags to the memory region unmapping operation that are not valid.

E44

Enclave console connection failure. The Nitro CLI failed to establish a connection with a running enclave's console. Make sure that the enclave has been started with the `--debug` flag.

E45

Enclave console read error. Failed to read from a running enclave's console. Retry the command.

E46

Enclave console write output error. Failed to write the information retrieved from a running enclave's console to a stream. Retry the command.

E47

Integer parsing error. Unable to connect to a running enclave's console because the CID could not be parsed. Use the `nitro-cli describe-enclaves` command to confirm the CID, and to ensure that it is a valid number.

E48

EIF building error. An error occurred while building the enclave image file. Review the error backtrace for more information.

E49

Docker image build error. An error occurred while building the enclave image file because the specified Docker image could not be built. Review the error backtrace for more information.

E50

Docker image pull error. An error occurred while building the enclave image file because the specified Docker image could not be pulled. Review the error backtrace for more information.

E51

Artifacts path environment variable not set. An error occurred while building the enclave image file because the artifacts path environment variable has not been set.

E52

Blobs path environment variable not set. An error occurred while building the enclave image file because the blobs path environment variable has not been set. Retry the command.

E53

Clock skew error. Failed to measure the elapsed time between consecutive reads from a running enclave's console. Retry the command.

E54

Signal masking error. Failed to mask specific signals after creating an enclave process. Retry the command.

E55

Signal unmasking error. Failed to unmask specific signals after creating an enclave process. Retry the command.

E56

Logger error. An error occurred while initializing the underlying logging system. Review the error backtrace for more information.

E57

Hasher error. An I/O error occurred while initializing a hasher or while writing bytes to the hasher.

E58

Naming error. The specified enclave name does not exist.

E59

EIF signature checker error. An error occurred while validating the signing certificate.

Document history

The following table describes important additions to the AWS Nitro Enclaves documentation. We also update the documentation frequently to address the feedback that you send us.

Change	Description	Date
Nitro Enclave networking and communication	Added a topic that describes how an enclave communicates with its parent instance over vsock, with tutorials for establishing a virtio-vsock channel and for decrypting a secret from inside the enclave using AWS KMS and cryptographic attestation.	July 13, 2026
Multiple enclaves per instance	You can run up to four Nitro Enclaves on a single parent Amazon EC2 instance.	January 13, 2023
Amazon EKS support	You can use Amazon Elastic Kubernetes Service to orchestrate, scale, and deploy Nitro Enclaves from a Kubernetes pod.	November 28, 2022
AWS Graviton support	Nitro Enclaves now supports AWS Graviton-based Amazon EC2 instance types, except A1, G5g, Im4gn, Is4gen, and T4g.	October 20, 2022
ACM for Nitro Enclaves	ACM for Nitro Enclaves now supports Apache HTTP server.	September 14, 2022
Nitro Enclaves 1.2.0 for Windows	Nitro Enclaves 1.2.0 is now available for Windows.	May 4, 2022

Amazon SNS topic for Nitro Enclaves for Windows updates	You can subscribe to an Amazon SNS topic to receive notifications for new versions of Nitro Enclaves for Windows.	August 13, 2021
Nitro Enclaves 1.1.0 for Windows	Nitro Enclaves 1.1.0 is now available for Windows.	July 28, 2021
Nitro Enclaves on Windows	Nitro Enclaves supports the creation of isolated compute environments form parent Amazon EC2 instances running Windows operating system.	April 27, 2021
Initial release	Initial release of AWS Nitro Enclaves. Nitro Enclaves is an Amazon EC2 feature that allows you to create isolated execution environments, called enclaves, from Amazon EC2 instances.	October 28, 2020