L4 – Security of Computer Systems

Evaluating data encryption on locally hosted open- source Amazon S3 compatible object storage platform

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Presentation

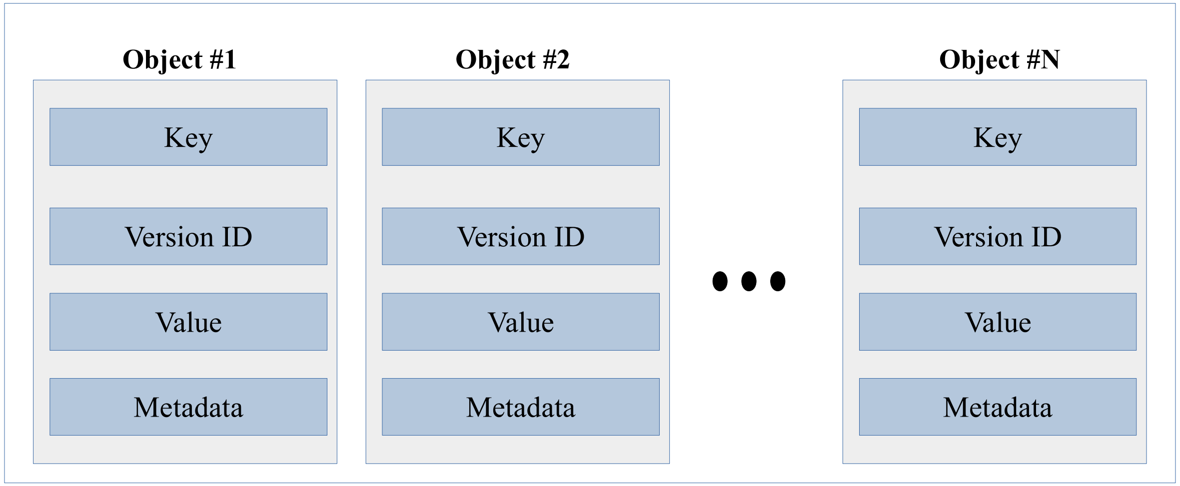
- Object Storage Systems
- Amazon Simple Storage Service
- MinIO Object Storage
- Threat Model
- Encryption Schemes
- Experimental Setup
- Performance Evaluation

Object Storage Systems

- Processing data as discrete units called objects.
- Objects are variable-length size and can be used to store all types of data (e.g., database records, medical records, system backup).
- Benefits:
  - Scalability: increase number of storage nodes.
  - Reduced complexity: removing unnecessary hierarchies.
  - Pay as you go: pricing is usually volume-based.
  - Cloud compatible

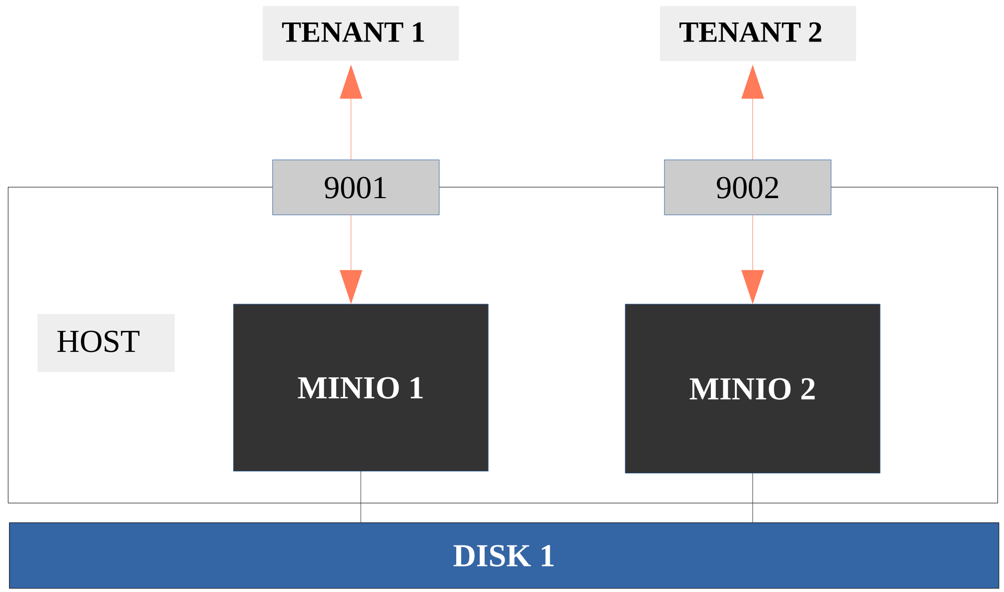
Amazon Simple Storage Service (Amazon S3)

- Amazon S3 is an object storage service provides high scalability, data availability, security and performance.
- Objects are stored and managed into buckets.
- Provides REST API for managing objects and buckets.
- Bucket architecture:



MinIO

- MinIO: High performance object dtorage released under Apache License v2.0
- API compatible with Amazon S3 cloud storage service.
- Deployment: a) Standalone, b) Distributed, and c) Cloud Scale.
- Multi-Tenant Standalone Deployment:



Accessing MinIO with TLS

- Transport Security Layer (TLS) enforces essential security guarantees:
  - Encryption: hides data being transferred.
  - Authentication: ensure identity of communicating parties.
  - Integrity: verifies the content of the transferred data.
- Communication with MinIO servers and clients is protected via TLS.
- MinIO server provides public certificate signed by a private key to establish communication.
- The certificate is provided through a Certificate Authority (CA) or is self-signed.

MinIO Encryption

- MinIO supports two types of Server-Side Encryption (SSE):
  - SSE-C: en/decrypting objects with client provided keys.
  - SSE-S3: object encryption keys are managed by a Key. Management System (KMS).
- For any encrypted object in the server there exist three keys:
  - OEK: unique key stored encrypted to en/decrypt an object
  - KEK: key to en/decrypt the OEK, is not stored anywhere
  - EK: external key, either client provided or managed by KMS
- Encryption algorithm: AES-256-GCM with keys 256 bits long.

Threat Model

- We focus on three kind of principals:
  - User: someone who want to securely store data online
  - Third-Party Service: an entity that claims or requests access to the user's data.
  - Cloud Storage Provider: a MinIO object storage server instance.
- Vulnerability: the third-party service gain access to an object's en/decryption keys through side-channel attacks e.g., cold boot attacks, and/or storage server is compromised.
- Goal: revoke access to the third-party service by introducing client side encryption schemes.

Client Side Encryption

```go
/* export encrypt */
func encrypt(fileToEncrypt string, fileName string, pathToKey string) *C.char{

	encrypted_file := fileName + ".bin"
	plaintext, err := ioutil.ReadFile(fileToEncrypt)

	/* Read key file content and convert it to string */
	content, err := ioutil.ReadFile(pathToKey)
	keyString := string(content)

	/* Decode key in order to get the key as type byte[] */
	key, _ := hex.DecodeString(keyString)

	/* Create a new Cipher Block from the key */
	block, err := aes.NewCipher(key)

	/* Create a new GCM */
	gcm, err := cipher.NewGCM(block)

	/* Never use more than 2^32 random nonces with a given key */
	nonce := make([]byte, gcm.NonceSize())
	if _, err := io.ReadFull(rand.Reader, nonce); err != nil {
		log.Fatal(err)
	}
	/* Encrypt the data using GCM Seal function */
	ciphertext := gcm.Seal(nonce, nonce, plaintext, nil)

	/* Save back to file */
	err = ioutil.WriteFile(encrypted_file, ciphertext, 0777)

	/* Returns a pointer to the encrypted file */
	return C.CString(encrypted_file)
}
```

```python
/* Loading C shared encryption library */
lib = cdll.LoadLibrary(“libencrypt.so”)

/* Structure that handles type convert between modules */
class go_string(Structure):
_fields_ = [
("p", c_char_p),
("n", c_int)]

/* Encryption function wrapper */
def encrypt(file_path, file_name, AES_KEY):
    lib.encrypt.restype = c_char_p
    fp = go_string(c_char_p(file_path.encode('utf-8')), len(file_path))
    key = go_string(c_char_p(AES_KEY.encode('utf-8')), len(AES_KEY))
    file_name = go_string(c_char_p(file_name.encode('utf-8')), len(file_name))
    encrypted_file_name = lib.encrypt(fp, file_name, key)

    /* Returns the name of the encrypted file */
    return encrypted_file_name
```

MinIO Server Side Encryption (SSE)

- Python client code for SSE-C encryption with client provided key.

```
/*  Encodes key and returns SSE configuration */
def sse_encryption(key):

    f = open(key, "r")
    key_str = f.read()
    key_str = key_str.replace('\n', '')
    key = key_str.encode('ascii')
    SSE = SseCustomerKey(key)

    return (SSE)

/* Custom HTTP client inquiring valid SSL certificate */
httpClient = urllib3.PoolManager(
                timeout=urllib3.Timeout.DEFAULT_TIMEOUT,
                        cert_reqs='CERT_REQUIRED',
                        ca_certs=PUBLIC_CERTIFICATE,
                        retries=urllib3.Retry(
                            total=5,
                            backoff_factor=0.2,
                            status_forcelist=[500, 502, 503, 504]
                        )
            )
/* MinIO Client initialized with access information */
client = Minio(MINIO_URL,
                    access_key='minio',
                    secret_key='minio123',
                    secure=True,
                    http_client=httpClient)

/* SSE Customer provided key encryption */
SSE = sse_encryption(key_path)

/* Clients putting object to server bucket with SSE encryption */
client.fput_object( BUCKET_NAME, file_name, file_path, sse=SSE )
```

Key Rotation

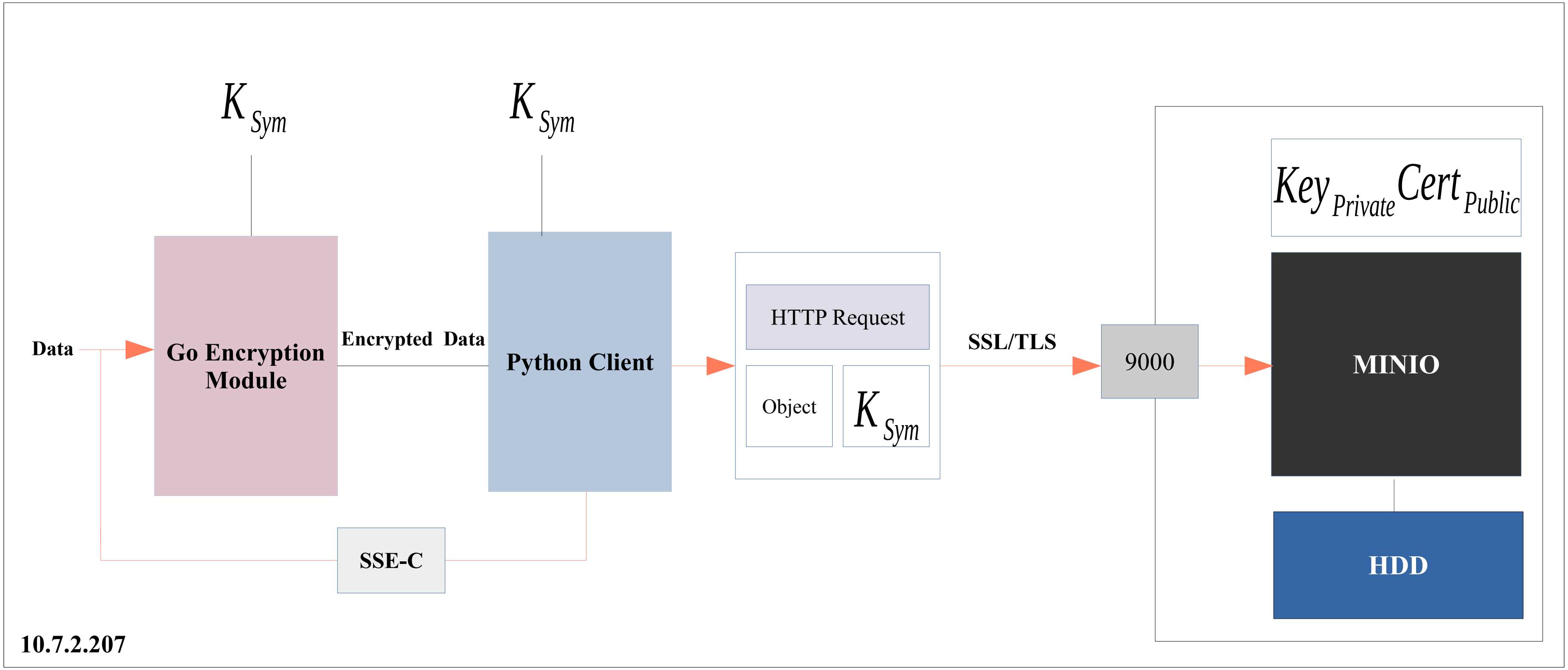
- MinIO supports a key rotation mechanism through a special HTTP COPY Request.
- Key Rotation:
  - Provide initial external secret key and a newly derived secret key.
  - Decrypt OEK with the old key and re-encrypt with the newly provided key.

```
/* Source object customer provided key */
SSE_SRC = sse_encryption(OLD_AES_KEY)

/* Destination Object SSE Customer provided key encryption */
SSE_DST = sse_encryption(NEW_AES_KEY)

/* Copy the object to the same bucket using a different key.
 * Object does not exit the server side using this method.
 */
result = client.copy_object(
    BUCKET_NAME,
    file_name,
    CopySource(BUCKET_NAME, file_name, ssec=SSE_SRC),
    sse=SSE_DST,
)
```

Experimental Setup

- Standalone deployment with a single storage server.
- Server equipped with 4 cores Intel (R) Core (TM) i5-4590 at 3.30 GHz and 7.7 GB of memory.
- Debian 10 64-bit Linux distribution 4.19.0-13-amd64
- OpenSSL version 1.1.1d.
- Go version go1.15.6 linux/amd64 and latest MinIO built from source.

System Architecture

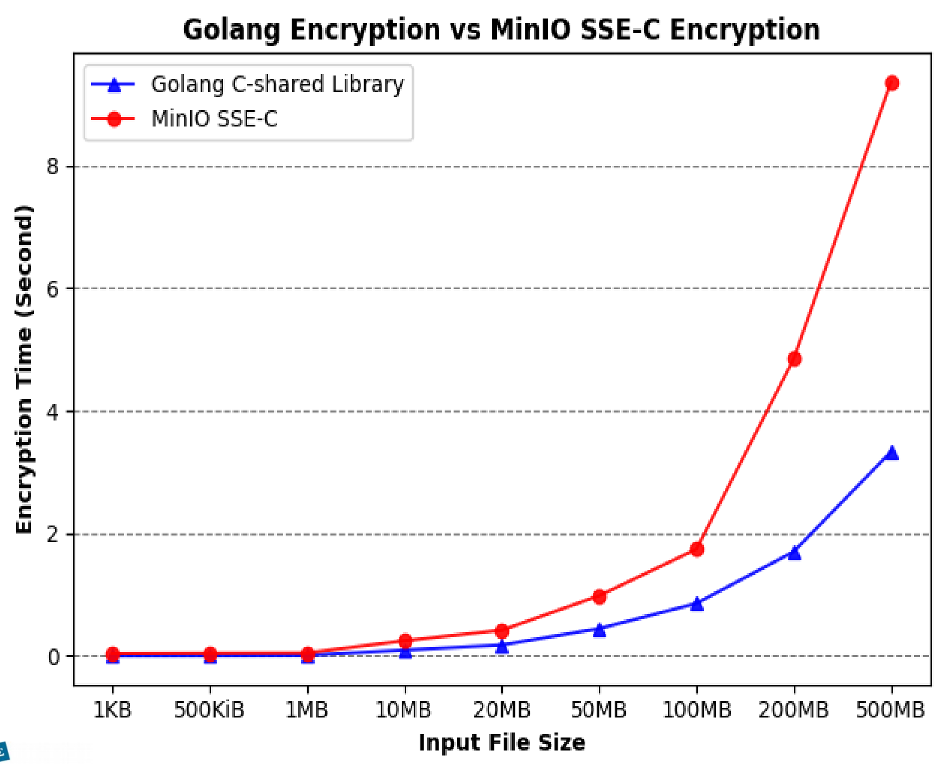


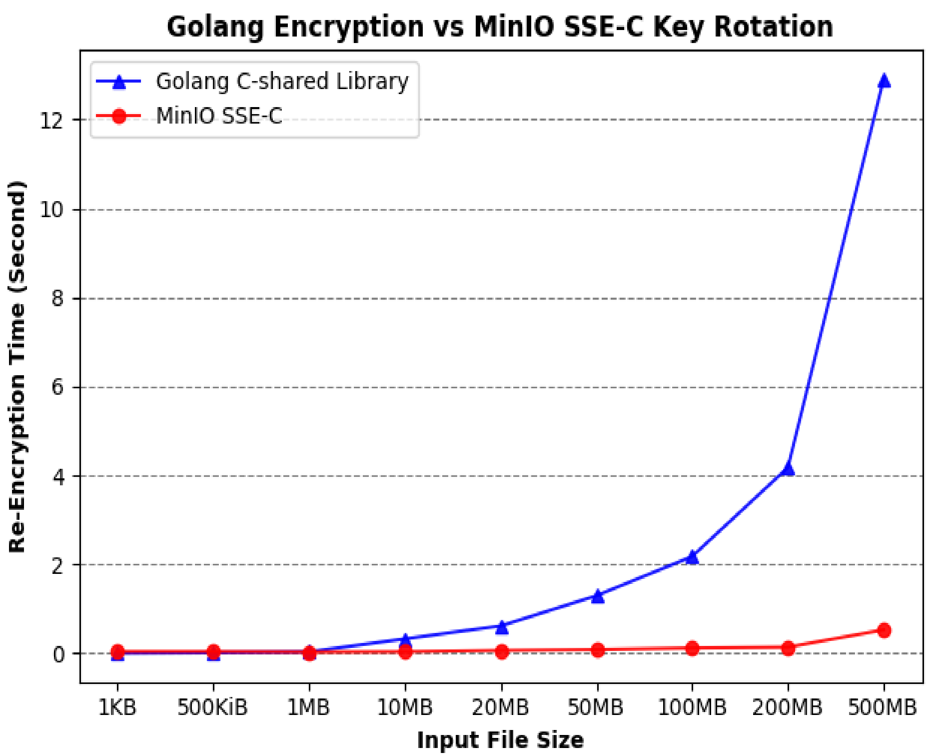
Performance Evaluation (1)

- Benchmark
  - Binary files ranging from 1KB up to 500 MB worth of data.
  - Runned tests 100 times for each input file.
  - Plotting median for encryption metrics and system resource utilization.
- Performance Metrics
  - Python's psutil for system resource utilization.
  - Encryption Time (second): time spent for encrypting input files.
  - Re-Encryption Time (second): time spent for client side re-encryption and SSE-C key rotation.
  - CPU Usage (%) and RAM Usage (%): system resource usage percentage during evaluation.

Performance Evaluation (2)

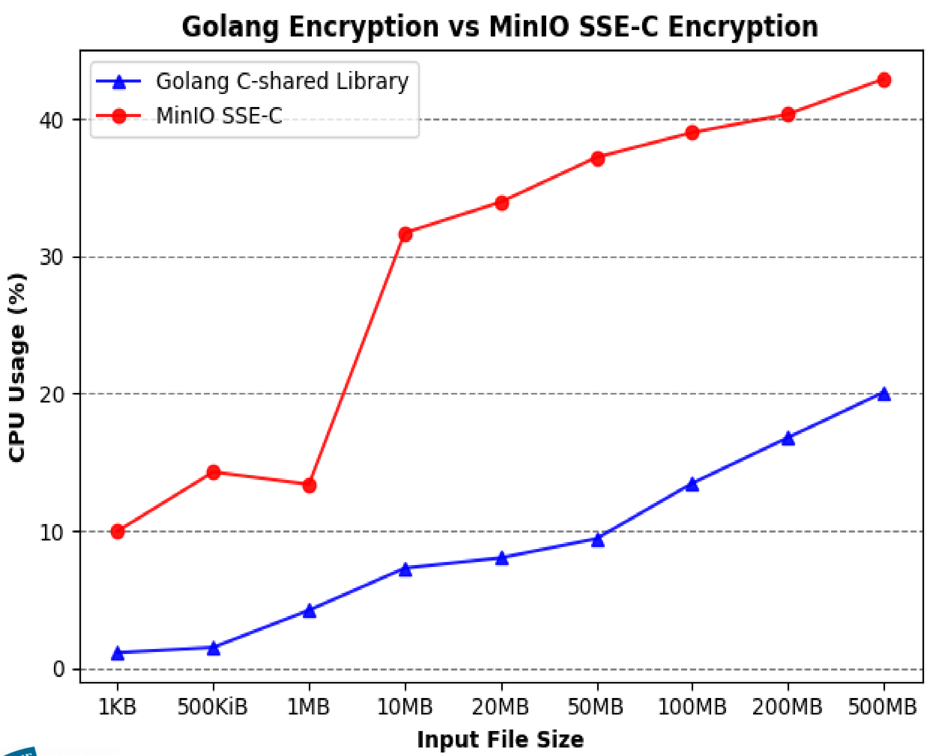
- Encryption Time and Re-Encryption Time of Golang client-side scheme and MinIO SSE-C.

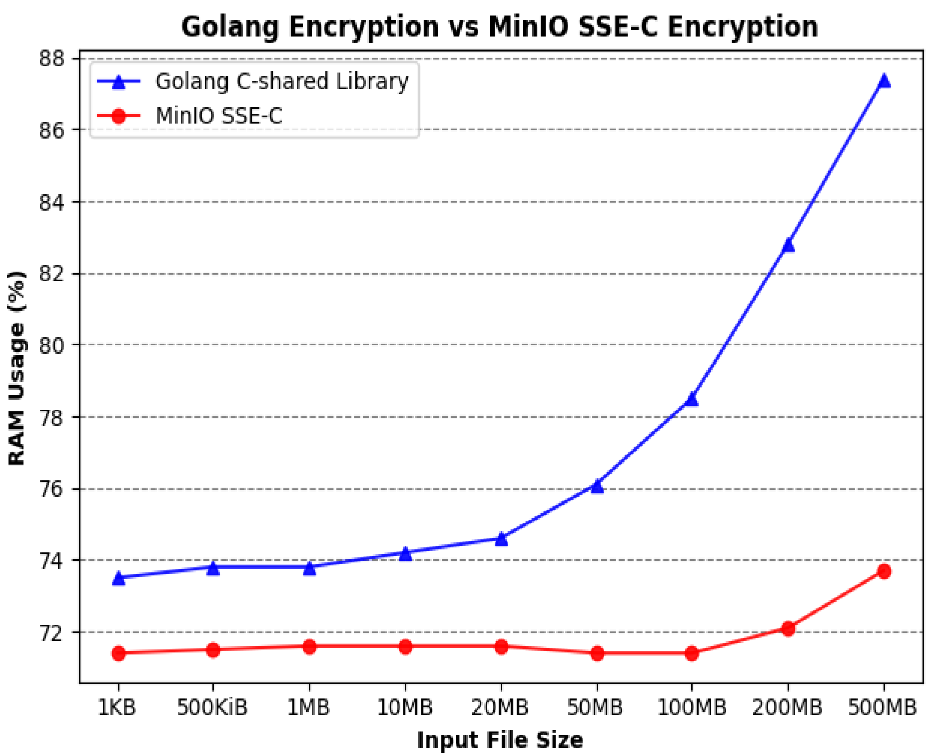




Performance Evaluation (3)

- CPU and RAM utilization of Golang encryption and MinIO SSE-C encryption.





Questions