Secure File Transfer System

RSA + AES Hybrid Encryption Protocol

Systems and Network Security Project

University Project

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Outline

1. Problem Description
2. Encryption Scheme
3. Communication Protocol
4. Features
5. Security Features
6. Demo
7. Conclusion

The Challenge: Secure File Storage

Problem Statement

How do we encrypt files when saving them on a remote server?

- Files need to be stored securely on the server
- The encryption key is **not known in advance**
- Each client session should have a unique encryption key
- Must prevent unauthorized access to stored files

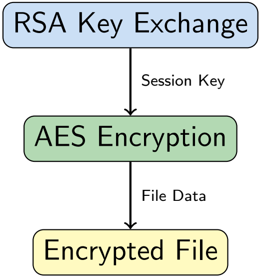
Security Requirements

- **Confidentiality**: Only authorized parties can read files
- **Integrity**: Detect any tampering with encrypted data
- **Key Exchange**: Securely share symmetric keys without prior setup

Solution: Hybrid Encryption (RSA + AES)

Why Hybrid?

- 🔑 RSA (Asymmetric)
  - Secure key exchange
  - No pre-shared secrets
  - 2048-bit keys
- 🔒 AES (Symmetric)
  - Fast data encryption
  - 256-bit keys
  - GCM mode (authenticated)



RSA Key Exchange

Session Key

AES Encryption

File Data

Encrypted File

Encryption Details

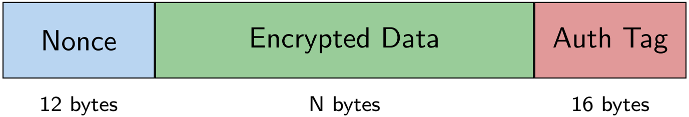
RSA-OAEP (Key Exchange Only)

- **Algorithm**: RSA with OAEP padding
- **Key Size**: 2048 bits
- **Hash Function**: SHA-512
- **Purpose**: Encrypt and transmit AES session key

AES-256-GCM (Data Encryption)

- **Algorithm**: AES in Galois/Counter Mode
- **Key Size**: 256 bits (32 bytes)
- **Nonce Size**: 12 bytes (unique per encryption)
- **Authentication Tag**: 128 bits (16 bytes)
- **Benefits**: Provides both confidentiality and integrity

AES-GCM Message Format



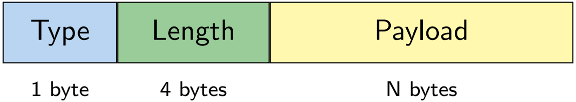
Nonce	Encrypted Data	Auth Tag
12 bytes	N bytes	16 bytes

- **Nonce**: Random value prepended to ciphertext
- **Encrypted Data**: AES-encrypted file content
- **Authentication Tag**: Verifies data integrity

Protocol Overview

Binary Protocol over TCP

- Custom binary format for efficiency
- TCP ensures reliable, ordered delivery
- Message-based communication

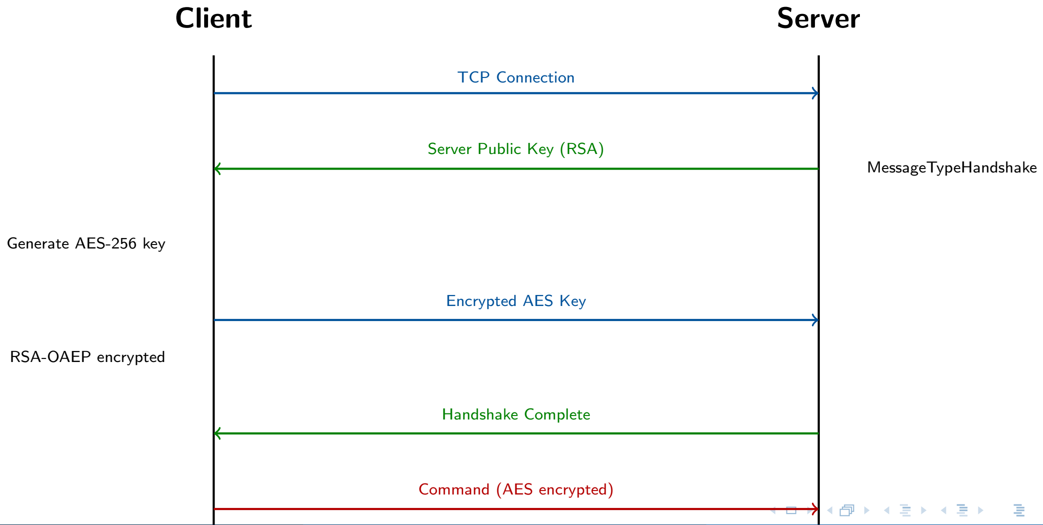


Type	Length	Payload
1 byte	4 bytes	N bytes

Message Types:

- 0x01: Handshake (RSA key exchange)
- 0x02: Command (file operations)
- 0x03: Data (chunked file transfer)
- 0x04: Response (server replies)

Connection Flow



Client

Server

TCP Connection

Server Public Key (RSA)

MessageTypeHandshake

Generate AES-256 key

Encrypted AES Key

RSA-OAEP encrypted

Handshake Complete

Command (AES encrypted)

Handshake Protocol

Step 1: Server → Client

```
Message Type: 0x01 (Handshake)
Payload: RSA Public Key (PEM format, 2048-bit)
```

Step 2: Client → Server

```
Message Type: 0x01 (Handshake)
Payload: AES-256 Key (encrypted with server's public key)
Encryption: RSA-OAEP with SHA-512
```

Result

Both client and server now share a unique **AES-256 session key** that will be used to encrypt all subsequent communication.

Available Commands

File Operations

- Upload (0x01) Upload a file to the server (encrypted with AES-256-GCM)
- Download (0x02) Download a file from the server (chunked transfer)
- List (0x03) List all files available in client's directory
- Delete (0x04) Delete a file from the server

All Data is Encrypted

Every file operation encrypts data using the session-specific AES-256-GCM key established during handshake.

Chunked File Transfer

For efficient large file transfers:

- Files are split into chunks (64 KB - 256 KB)
- Each chunk includes progress information:
  - Chunk index (current chunk number)
  - Total chunks (how many total)
  - Chunk size (bytes in this chunk)
  - Total file size
- Adaptive chunk sizing based on file size:
  - Small files ($<$ 256 KB): 64 KB chunks
  - Medium files ($<$ 5 MB): 128 KB chunks
  - Large files ($\geq$ 5 MB): 256 KB chunks

Benefits

✓ Memory efficient ✓ Progress tracking ✓ Network optimization

Command Message Format

Upload Command Example:

Command	Name Len	Filename	Encrypted Data
1 byte	2 bytes	N bytes	M bytes

Response Message Format:

Success	Msg Len	Message	Data
1 byte	2 bytes	N bytes	M bytes

Path Traversal Protection

Vulnerability: Path Traversal Attack

Malicious clients might try to access files outside their directory:

- `../../../etc/passwd`
- `/etc/shadow`
- `../../config/private.pem`

Our Protection Mechanism

1. **Reject absolute paths**: Only relative paths allowed
2. **Clean and resolve paths**: Use `filepath.Clean()` and `filepath.Abs()`
3. **Verify containment**: Ensure resolved path starts with root directory
4. **Reject empty filenames**: Prevent directory access

`validatePath()` function ensures all file operations stay within bounds!

Path Validation Code

```go
func (h *CommandHandler) validatePath(filename string) (string, error) {
    // Reject empty filenames
    if filename == "" {
        return "", fmt.Errorf("filename cannot be empty")
    }

    // Reject absolute paths
    if filepath.IsAbs(filename) {
        return "", fmt.Errorf("absolute paths not allowed")
    }

    // Get client’s root directory
    rootDir, _ := h.getClientDir()
    absRoot, _ := filepath.Abs(rootDir)

    // Build and clean full path
    fullPath := filepath.Join(absRoot, filename)
    cleanPath := filepath.Clean(fullPath)
    absPath, _ := filepath.Abs(cleanPath)

    // Ensure path is within root directory
    if !strings.HasPrefix(absPath, absRoot+string(filepath.Separator)) {
        return "", fmt.Errorf("path traversal detected")
    }

    return absPath, nil
}
```

Per-Client Session Storage

Isolation Strategy

Each client gets a unique directory based on their session key:

1. Compute SHA-256 hash of the AES session key
2. Use first 16 hex characters as directory name
3. Create directory: `data/<client_hash>/`
4. All file operations restricted to this directory

Benefits:

- ✓ Client isolation
- ✓ No shared storage
- ✓ Session-based access
- ✓ Automatic organization

Example

```
data/
  1e8130cada7a548b/
  a30155fdb2c96dab/
  c45ff82a901b43ef/
```

Additional Security Features

1. **Authenticated Encryption**
   - AES-GCM provides both encryption and authentication
   - Any tampering with ciphertext is detected
   - 128-bit authentication tag prevents forgery
2. **Unique Nonces**
   - Each encryption operation uses a fresh 12-byte nonce
   - Prevents replay attacks
   - Cryptographically secure random generation
3. **Session-Based Keys**
   - New AES key for each connection
   - Keys never stored on disk
   - Limits impact of key compromise

Security Analysis

Implemented Protections

- ✓ RSA-2048 for secure key exchange
- ✓ AES-256-GCM for authenticated encryption
- ✓ Path traversal prevention
- ✓ Per-client storage isolation
- ✓ Unique nonces for each encryption
- ✓ Session-based encryption keys

Potential Improvements

- ✗ No mutual authentication (vulnerable to MITM)
- ✗ No perfect forward secrecy (same RSA key reused)
- ✗ No replay protection (no sequence numbers)
- ✗ No user authentication system

Demo: Starting the Server

Build and run the server:

```
# Build the server
make server
# OR
go build -o bin/server cmd/server/main.go

# Run server with default settings (localhost:8080)
./bin/server

# Run with custom port
./bin/server -port 9000

# Run with custom host and data directory
./bin/server -host 0.0.0.0 -port 8080 -root-dir data
```

Server automatically:

- Generates RSA keys (if not exist)
- Creates data directories

Demo: Client Usage

Build and connect to server:

```
# Build the client
make client
# OR
go build -o bin/client cmd/client/main.go

# Connect to server
./bin/client -host localhost -port 8080
```

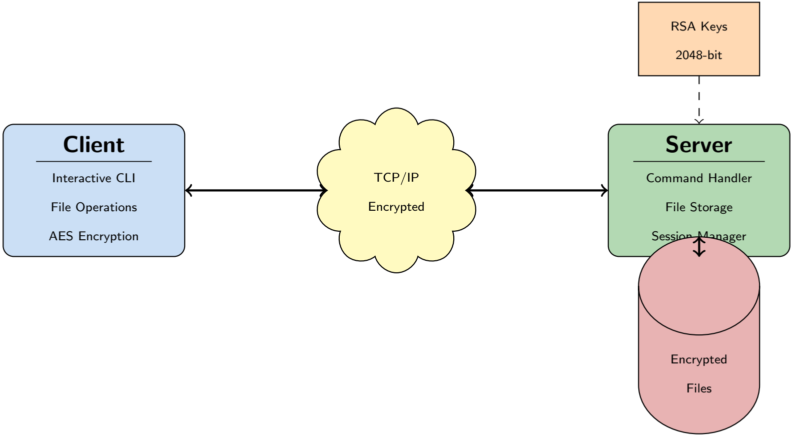
Available commands:

```
> upload myfile.txt        # Upload a file
> download myfile.txt      # Download a file
> list                     # List all files
> delete myfile.txt        # Delete a file
> help                     # Show help
> exit                     # Disconnect
```

Demo: Interactive Session

```
$ ./bin/client -host localhost -port 8080

Connected to server successfully!
Handshake completed. Session secured with AES-256-GCM.

Available commands: upload, download, list, delete, help, exit

> upload test.txt
File ’test.txt’ uploaded successfully

> list
Files on server:
test.txt

> download test.txt output.txt
Downloading file in chunks...
[====================================] 100%
File downloaded to ’output.txt’ (1024 bytes)

> delete test.txt
Are you sure you want to delete ’test.txt’? (y/n): y
File ’test.txt’ deleted successfully

> exit
Goodbye!
```

System Architecture Diagram



Summary

Project Achievements

- **Secure file transfer system** with hybrid encryption
- **RSA-2048 + AES-256-GCM** for key exchange and data encryption
- **Custom binary protocol** over TCP for efficiency
- **Complete command set**: upload, download, list, delete
- **Security features**: path traversal protection, per-client isolation
- **Optimized transfers**: chunked download with progress tracking

Key Takeaways

- Hybrid encryption combines best of symmetric and asymmetric crypto
- Proper input validation is critical for server security
- Session-based isolation prevents unauthorized access
- Authenticated encryption (GCM) provides confidentiality and integrity

Future Enhancements

1. **Mutual Authentication**
   - Certificate-based authentication
   - Prevent man-in-the-middle attacks
2. **Perfect Forward Secrecy**
   - Implement ephemeral Diffie-Hellman key exchange
   - Protect past sessions if keys compromised
3. **User Management**
   - Multi-user support with authentication
   - Role-based access control
4. **Performance Optimizations**
   - Parallel chunk transfers
   - Compression before encryption
   - Resume interrupted transfers

Technologies Used

Programming Language:

- Go (Golang) 1.21+

Cryptography:

- `crypto/rsa`: RSA key generation
- `crypto/aes`: AES encryption
- `crypto/cipher`: GCM mode
- `crypto/sha256`: Hashing
- `crypto/sha512`: RSA-OAEP

Networking:

- `net`: TCP socket programming
- `bufio`: Buffered I/O

Utilities:

- `go.uber.org/zap`: Structured logging
- `encoding/binary`: Binary protocol
- `filepath`: Path manipulation

Repository Structure: Well-organized Go project with `cmd/`, `pkg/`, and clear separation of concerns

Thank You!

Questions?

Secure File Transfer System
RSA + AES Hybrid Encryption

github.com/lcensies/ssnproj