scapi Documentation

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Contents

SCAPI is an open-source Java library for implementing secure two-party and multiparty computation protocols (SCAPI stands for the "Secure Computation API"). It provides a reliable, efficient, and highly flexible cryptographic infrastructure. SCAPI also has a c++ version - currently in beta. SCAPI is free and is licensed under an adaptation of the MIT license, you can read more about the license *here*.

CHAPTER 1

SCAPI Documentation

Introduction

SCAPI is an *open-source* general library tailored for **Secure Computation** implementations. SCAPI provides a flexible and efficient infrastructure for the implementation of secure computation protocols, that is both easy to use and robust. We hope that SCAPI will help to promote the goal of making secure computation practical.

Why Should I Use SCAPI?

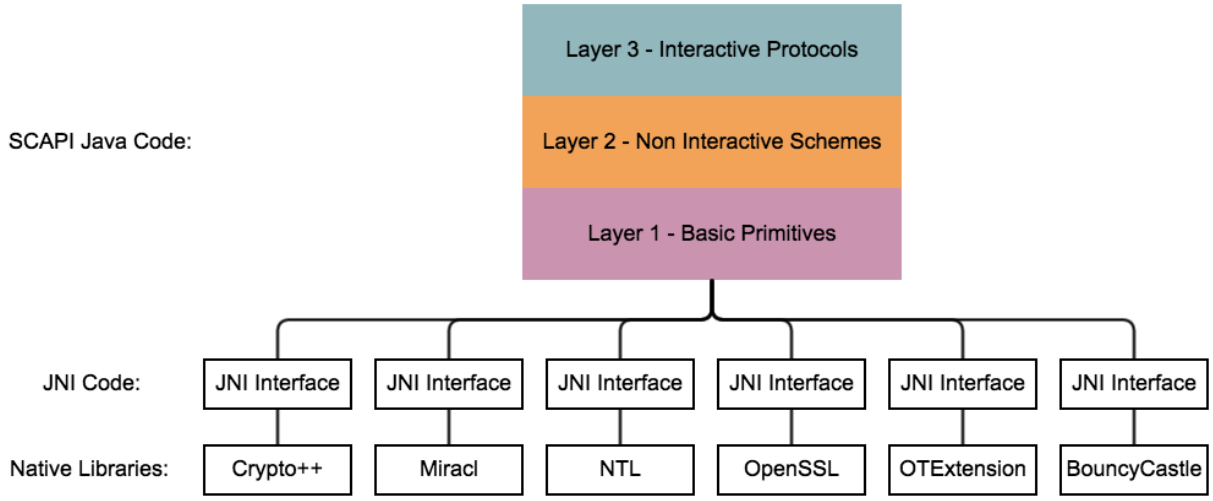
- **SCAPI provides uniformity.** As of today, different research groups are using different implementions. It is hard to compare different results, and implementations carried out by one group cannot be used by others. SCAPI is trying to solve this problem by offering a modular codebase to be used as the standard library for Secure Computation.
- **SCAPI is flexible.** SCAPI's lower-level primitives inherit from modular interfaces, so that primitives can be replaced easily. SCAPI leaves the choice of which concrete primitives to actually use to the high-level application calling the protocol. This flexibility can be used to find the most efficient primitives for each specific problem.
- **SCAPI is efficient.** Most of SCAPI's low level code is built upon native C/C++ libraries using JNI (the java native interface) in order to run more efficiently. For example, elliptic curve operations in SCAPI are implemented using the extremely efficient Miracl library written in C.
- **SCAPI is built to please.** SCAPI has been written with the understanding that others will be using it, and so an emphasis has been placed on clean design and coding, documentation, and so on.

Architecture

SCAPI is composed of the following three layers:

1. **Low-level primitives:** these are functions that are basic building blocks for cryptographic constructions (e.g., pseudorandom functions, pseudorandom generators, discrete logarithm groups, and hash functions belong to this layer).
2. **Non-interactive mid-level protocols**: these are non-interactive functions that can be applications within themselves in addition to being tools (e.g., encryption and signature schemes belong to this layer).
3. **Interactive mid-level protocols:** these are interactive protocols involving two or more parties; typically, the protocols in this layer are popular building blocks like commitments, zero knowledge and oblivious transfer.

In addition to these three main layers, there is an orthogonal communication layer that is used for setting up communication channels and sending messages.



Installation

Scapi is simple enough to install, the installation varies on different operating systems. Scapi currently supports Linux, Mac OS X, and Windows.

Prerequisites on Linux

There are a few prerequisites you must install before being able to compile scapi on your machine.

1. Install git
2. Install java, junit4, and ant
3. Install the gcc compiler environment: *gcc*, *make*, *ar*, *ld*, etc. Under Ubuntu you can simply run `sudo apt-get install build-essential`.

On Ubuntu environment is should look like:

```
$ sudo apt-get update
$ sudo apt-get install git
$ sudo apt-get install default-jre
$ sudo apt-get install default-jdk
$ sudo apt-get install build-essential
$ sudo apt-get install ant
$ sudo apt-get install junit4
```

Note: Notice that scapi should compile with gcc 4.7 or higher (if you also compile the c++ version - see specific instruction in c++ section)

Prerequisites on Mac OS X

On Mac OS X, git is usually preinstalled, and so are java and the gcc compiler environment. However, ant is not preinstalled, and you must install it via homebrew:

```
$ brew install ant
```

Prerequisites OS X 10.9 (Mavericks) and above

Starting in OS X Mavericks, apple has switched the default compiler from gcc to clang. Since Scapi's buildsystem is based on gcc, you must install gcc manually using homebrew:

```
$ brew tap homebrew/versions
$ brew install gcc49
```

Note: Homebrew compiles gcc from source, and it can take a lot of time (usually around 20-50 minutes). **DO NOT** stop the shell process even though it seems to be stuck, it's not stuck.

Installing Scapi from Source (On UNIX-based Operating Systems)

In order to install scapi:

```
$ git clone git://github.com/cryptobiu/scapi.git
$ cd scapi
$ git submodule init
$ git submodule update
$ sudo make prefix=/usr
$ sudo make install prefix=/usr
```

In case you want to install the latest java build as well and not use the pre-compiled header:

```
$ sudo make compile-scapi
```

Note: Seems that JDK 1.8 introduced a change of behavior regarding JNI include file locations. Details on the problem and workaround can be found in the following link: jdk-1-8-on-linux

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Instructions for Windows

We currently do not have a makefile for windows, but we intend to add one in the near future.

In order to use SCAPI on windows, we included precompiled assets on the **assets/** dir.

Needed Files

1. ScapiWin-{version}.jar (Scapi)
2. bcprov-{version}.jar (Bouncy Castle)
3. commons-exec-{version}.jar (Apache Commons utilities)
4. activemq-all-{version}.jar (Apache ActiveMQ ™ is an open source messaging and Integration Patterns server)
5. Precompiled DLLs under win32Dlls (for 32-bit windows) or under x64Dlls (for 64-bit windows)
6. msvcp100.dll, msvcr100.dll, msvcp120.dll and msvcr120.dll(Microsoft DLLs used by the native code)

In order to install SCAPI

On Eclipse:

1. Configure build path: go to Libraries tab, and add external JARS.
   (a) Add ScapiWin-{version}.jar.
   (b) Add bcprov-{version}.jar.
   (c) Add commons-exec-{version}.jar.
   (d) Add activemq-all-{version}.jar
2. Configure build path: go to Source tab and locate the Native Library Location section.
   (a) Add the lib folder where you have the precompiled DLLs (assets/win32Dlls or assets/x64Dlls).
3. Place the msvcp100.dll and msvcr100.dll in [C:]WindowsSystem32 folder if they are missing there.

Quickstart

Eager to get started? This page gives a good introduction to SCAPI. It assumes you already have SCAPI installed. If you do not, head over to the *Installation* section.

Your First Scapi Application

We begin with a minimal application and go through some basic examples.

```
import java.io.IOException;
import java.math.BigInteger;
import java.security.SecureRandom;

import org.bouncycastle.util.BigIntegers;

import edu.biu.scapi.primitives.dlog.DlogGroup;
import edu.biu.scapi.primitives.dlog.GroupElement;
import edu.biu.scapi.primitives.dlog.openSSL.OpenSSLDlogECF2m;

public class DlogExample {

    public static void main(String[] args) throws IOException {
        // initiate a discrete log group
        // (in this case the OpenSSL implementation of the elliptic curve group K-233)
        DlogGroup dlog = new OpenSSLDlogECF2m("K-233");
        SecureRandom random = new SecureRandom();

        // get the group generator and order
        GroupElement g = dlog.getGenerator();
        BigInteger q = dlog.getOrder();
        BigInteger qMinusOne = q.subtract(BigInteger.ONE);

        // create a random exponent r
        BigInteger r = BigIntegers.createRandomInRange(BigInteger.ZERO, qMinusOne, random);

        // exponentiate g in r to receive a new group element
        GroupElement g1 = dlog.exponentiate(g, r);
        // create a random group element
```

```
        GroupElement h = dlog.createRandomElement();
        // multiply elements
        GroupElement gMult = dlog.multiplyGroupElements(g1, h);
    }
}
```

Pay attention to the definition of the discrete log group. In Scapi we will always use a generic data type such as `DlogGroup` instead of a more specified data type. This allows us to replace the group to a different implementation or a different group entirely, without changing our code.

Let's break it down:

We first imported the needed classes that are built-in in java. Scapi uses heavily the `SecureRandom` class. This class provides a cryptographically strong random number generator (RNG). We also use the `BigInteger` type to handle big numbers. Since java has such class we do not need to re-implement it in Scapi.

```
import java.math.BigInteger;
import java.security.SecureRandom;
```

We import the BouncyCastle utility class `BigIntegers` that provide a very convenient function to generate a random big integer in a given range.

```
import org.bouncycastle.util.BigIntegers;
```

We import the Scapi generic primitives `DlogGroup` (implements a discrete log group) and `GroupElement` (a group member). We then import the `OpenSSLDlogECF2m` class. This is a wrapper class to a native implementation of an elliptic curve group in the OpenSSL library. Since `GroupElement` and `DlogGroup` are interfaces, we can easily choose a different group without changing a single line of code except the one in emphasis.

```
import edu.biu.scapi.primitives.dlog.DlogGroup;
import edu.biu.scapi.primitives.dlog.GroupElement;
import edu.biu.scapi.primitives.dlog.openSSL.OpenSSLDlogECF2m;
```

Our main class defines a discrete log group, and then extract the group properties (generator and order).

```
public class DlogExample {

    public static void main(String[] args) throws IOException {
        // initiate a discrete log group
        // (in this case the OpenSSL implementation of the elliptic curve group K-233)
        DlogGroup dlog = new OpenSSLDlogECF2m("K-233");
        SecureRandom random = new SecureRandom();

        // get the group generator and order
        GroupElement g = dlog.getGenerator();
        BigInteger q = dlog.getOrder();
        BigInteger qMinusOne = q.subtract(BigInteger.ONE);

        ...
    }
}
```

We then choose a random exponent, and exponentiate the generator in this exponent.

```
// create a random exponent r
BigInteger r = BigIntegers.createRandomInRange(BigInteger.ZERO, qMinusOne, random);
```

```
// exponentiate g in r to receive a new group element
GroupElement g1 = dlog.exponentiate(g, r);
```

We then select another group element randomly.

```
// create a random group element
GroupElement h = dlog.createRandomElement();
```

Finally, we demonstrate how to multiply group elements.

```
// multiply elements
GroupElement gMult = dlog.multiplyGroupElements(g1, h);
```

Compiling and Running the Scapi Code

Save this example to a file called *DlogExample.java*. In order to compile this file, type in the terminal:

```
$ scapic DlogExample.java
```

The `scapic` command is created during the installation of scapi, and is used instead of the `javac` command. In reality, `scapic` is actually a shortcut to `javac` with the Scapi jar files appended to the java *classpath*.

A file called *DlogExample.class* should be created as a result. In order to run this file, type in the terminal:

```
$ scapi DlogExample
```

Like `scapic`, `scapi` replaces the `java` command, and defines the java classpath correctly as well as import the scapi jni interface shared libraries.

Establishing Secure Communication

The first thing that needs to be done to obtain communication services is to setup the connections between the different parties. Each party needs to run the setup process at the end of which the established connections are obtained. The established connections are called *channels*.

The `CommunicationSetup` Classes are responsible for establishing secure communication to other parties. An application requesting from `CommunicationSetup` to prepare for communication needs to call the `CommunicationSetup::prepareForCommunication()` function:

Map<String, Channel> **`prepareForCommunication`** (List<PartyData> *listOfParties*, long *timeOut*)

Parameters

- **listOfParties** (*List<PartyData>*) – The list of parties to connect to. As a convention, we will set the first party in the list to be the requesting party, that is, the party represented by the application.
- **timeOut** (*long*) – A time-out (in milliseconds) specifying how long to wait for connections to be established and secured.

Returns a map of the established channels.

Let's add the following method to the `DlogExample` class:

```
import java.net.InetSocketAddress;
import java.util.List;
import java.util.Map;

import java.util.concurrent.TimeoutException;
```

```
import edu.biu.scapi.comm.Channel;
    import edu.biu.scapi.comm.twoPartyComm.LoadSocketParties;
    import edu.biu.scapi.comm.twoPartyComm.NativeSocketCommunicationSetup;
    import edu.biu.scapi.comm.twoPartyComm.PartyData;
    import edu.biu.scapi.exceptions.DuplicatePartyException;

private static Channel setCommunication() throws TimeoutException, DuplicatePartyException {
        //Prepare the parties list.
        LoadSocketParties loadParties = new LoadSocketParties("Parties0.properties");
        List<PartyData> listOfParties = loadParties.getPartiesList();

        //Create the communication setup.
        NativeSocketCommunicationSetup commSetup = new NativeSocketCommunicationSetup(listOfParties

        long timeoutInMs = 60000;  //The maximum amount of time we are willing to wait to set a con
        int numberOfChannels = 1;  //The number of required channels.

        Map<String, Channel> connections = commSetup.prepareForCommunication(numberOfChannels, timeo

        // prepareForCommunication() returns a map with all the established channels,
        // we return only the first one since this code assumes the two-party case.
        return connections.values().iterator().next();
    }
```

In this example, the list of parties is read from a properties file called *Parties0.properties*:

```
# A configuration file for the parties

NumOfParties = 2

IP0 = 127.0.0.1
IP1 = 127.0.0.1

Port0 = 8001
Port1 = 8000
```

A `Channel` represents an established connection between two parties. A channel can have Plain, Encrypted or Authenticated security level, depending on the requirements of the application. In all cases the channel has two main functions:

public void **`send`**(Serializable *data*)
: Sends a message *msg* to the other party, *msg* must be a `Serializable` object.

public Serializable **`receive`**()
: Receives a message from the channel. Conversion to the right type is the responsiblity of the caller.

This means that from the applications point of view, once it obtains the channels and sets their Security Level it can completely forget about it and just send and receive messages knowing that all the encryption or authentication work is done automatically.

The Communication Layer

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Communication Design

The communication layer provides communication services for any interactive cryptographic protocol. The basic communication channel is plain (unauthenticated and unencrypted). Secure channels can be obtained using TLS or by using a pre-shared symmetric key. This layer is heavily used by the interactive protocols in SCAPI' third layer and by MPC protocols. It can also be used by any other cryptographic protocol that requires communication. The communication layer is comprised of two basic communication types: a two-party communication channel and a multiparty layer that arranges communication between multiple parties.

Two-Party communication

The two party communication layer provides a way to setup a two-party channel and communicate between them. This implementation improves on the previous SCAPI two-party channel in the following aspects:

- The user can choose between three different channel types: a socket-based channel, a queue-based channel, and a TLS channel (for each of the socket and queue options). Each option has it own advantages and disadvantages,

and the user should analyze which channel is most appropriate. In general, a queue is a more robust channel, but is less efficient than a socket channel.

- The queue channels avoid, or more accurately automatically recover from, communication failures. Thus, an application that needs to be robust and recover from such failures should use the queue channel.
- TLS/SSL is used for providing secure communication. (In many cases, this is more convenient than the previous SCAPI channel which used SCAPI encryption and authentication and thus required preshared keys.)
- Any number of channels can be established between a single pair of parties. Each party provides the number of channels that are desired, and the communication setup function returns a map containing this number of channels. This is very important for multithreading (e.g., SCAPI oblivious transfer protocols receive a channel in their constructor; in order to run many OTs in parallel, it is necessary to generate a different channel for each thread). We stress that only one port is needed, even if many channels are created. The different channels have unique internal port numbers, but use only a single external port number.

All the classes in the two-party communication are in the `edu.biu.scapi.twoPartyComm` package.

Plain communication

This type of channel delivers every message as is, without encryption or authentication. It is possible to encrypt and/or authenticate the channel by wrapping the channel with SCAPI's encrypted and/or authenticated channel at scapi.edu.biu.comm. (Note that this requires pre-shared symmetric keys.) Alternatively, the SSL communication can be used instead, as described below.

There are two different implementations of the plain communication channel: socket communication and queue communication.

Socket communication This implementation of a plain communication channel uses the `Socket` and `ServerSocket` of the `java.net` package.

Internally, there are two sockets for each channel: one socket for sending messages (sendSocket) and another socket to receive messages (receiveSocket). This mechanism makes the communication more convenient and easy to understand.

The class that implements this communication type is called `SocketCommunicationSetup`.

Queue communication This implementation of a plain communication channel uses the JMS API for sending and receiving messages.

JMS enables distributed communication that is loosely coupled. A component sends a message to a destination, and the recipient can retrieve the message from the destination. However, the sender and the receiver do not have to be available at the same time in order to communicate. In fact, the sender does not need to know anything about the receiver; nor does the receiver need to know anything about the sender. The sender and the receiver only need to know which message format and which destination to use. In this respect, messaging differs from tightly coupled technologies, like Remote Method Invocation (RMI), which requires an application to know a remote application's methods. Moreover, the JMS API knows how to automatically recover from communication failures; in case a connection falls during the communication, it is automatically reconnected. In addition, messages cannot get lost in the communication. A queue is therefore a far more robust method of communication.

In SCAPI's implementation, the server manages two queues between each pair of parties P1 and P2: one of them is used for P1 to send messages and for P2 to receive them, and the other is used for P2 to send messages and for P1 to receive them.

The class that implements this communication type is called `QueueCommunicationSetup`. This class gets a ConnectionFactory in the constructor and uses it to create the JMS connection. This allows us to deal with every JMS implementation. In addition, we provide a concrete implementation that uses ActiveMQ implementation of JMS

that creates the factory inside the constructor. Thus, the user can use this class instead of dealing with the factory construction.

Note: In order to use Queue-based communication, a queue server needs to be configured, and up and running. We remark, however, that the queue server can be run by one of the parties if desired and so no additional machines are actually needed.

SSL communication

In this type of channel, the establishment of the secure channel, and the encryption and authentication are carried out by the TLS protocol. The implementation uses mutual (client and server) authentication and so both parties need certificates. The protocol version used is TLS v1.2 and forward-secure cipher suites are used.

Note: TLS v1.2 is supported from Java 7 only. In order to use the SSL channel, you need to make sure that you have at least Java 7 installed.

The security of SSL relies on the ability of each party to validate that it has received the authentic certificate of the other party. We support two ways to validate the other party's certificate. The first is to use a CA-signed certificate and carry out the validation using the CA certificate in the party's existing certificate store. The second is to use a self-signed certificate and carry out the validation using a method called "certificate pinning" which just means that it is assumed that each party already has the other party's certificate and trusts it. We now describe these two methods:

- CA-signed certificate

  With this method, it is assumed that the parties have certificates that were signed by a trusted CA. In order to validate the authenticity of the certificate, the protocol takes the CA key from the trustStore and verifies that the certificate is indeed signed by the CA and is therefore valid.

  The steps that should be taken in order to work with a CA certificate are as follows:

  1. Open cmd and go to your JAVA_HOME path. For example:

     ```
     >> cd C:\Program Files\Java\jre6\bin
     ```

  2. Generate a key store:

     ```
     >> keytool -genkey -alias {your_domain} -keyalg RSA -keysize 2048 -keypass changeit -keystor
     ```

  3. Create a certificate request to send to the CA:

     ```
     >> keytool -certreq -alias {your_domain} -keystore scapiKeystore.jks -file scapiCert.csr
     ```

  4. The Certificate Signing Request that you generated can be submitted to a CA to create a certificate signed by the CA.

     Note: You must obtain the signed certificated from the CA before carrying out the following steps.

     ---

  5. Install the CA root and any intermediate certificates into the keystore:

     ```
     >> keytool -import -trustcacerts -alias {root_certificate_alias} -file root.crt -keystore sc
     ```

  6. Install the generated server certificate into the keystore:

     ```
     >> keytool -import -trustcacerts -alias <server_certificate_alias> -file scapiCert.crt -keys
     ```

  7. Install the CA root and any intermediate certificates into the truststore:

```
>> keytool -import -trustcacerts -alias {root_certificate_alias} -file root.crt -keystore sc
```

8. After you have the scapiKeystore.jks and scapiCacerts.jks files, put them in your project root directory.

After the CA certificate has been installed, the parties can use any certificate signed by that CA without any further manual setup.

- Self-signed certificate and certificate pinning

  With this method, the users sign the certificates themselves and send them to the other parties in some out-of-band communication before running the protocol. It is assumed that the parties manually validate the authenticity of the certificates (e.g., by comparing their fingerprints over the phone). Each party has two certificates. The first is the certificate that the party generated itself; this should be installed in the keyStore. The second is the certificate that it received from the other party; this certificate should be installed in the trustStore, and declared as "trusted". During the SSL handshake, each party receives the certificate of the other party. Since this certificate was already declared as "trusted", SSL accepts the certificate as valid. Each party is responsible to generate its own self-signed certificate, put it in its keystore and send it to the other party. Moreover, each party must receive the self-signed certificate of the other party and put it in its truststore.

  To help with the certificate generation process, we describe here the exact steps that should be taken:

  1. Open cmd and go to your JAVA_HOME path. For example:

     ```
     >> cd C:\Program Files\Java\jre6\bin
     ```

  2. Generate a self signed certificate and put it in the key store:

     ```
     >> keytool -genkey -alias {your_domain} -keyalg RSA -keysize 2048 -keypass changeit -keystor
     ```

  3. Get the certificate file from the key store in order to send it to the other party:

     ```
     >> keytool -export -alias {your_domain} -storepass changeit -file myCert.cer -keystore scapi
     ```

  4. When receiving the other party's certificate:

     ```
     >> keytool -import -v -trustcacerts -alias {other_party_domain} -file otherCert.cer -keystor
     ```

  5. After you have the scapiKeystore.jks and scapiCacerts.jks files, put them in your project root directory.

There are two different implementations of the SSL communication channel: SSL socket communication and SSL queue communication.

SSL socket communication This is a special case of socket communication that uses an SSL socket instead of a plain one. This implementation uses the `SSLSocket` and `SSLServerSocket` of `javax.net.ssl` package.

This implementation loads the scapiKeystore.jks and scapiCacerts.jks mentioned above. The names of the files are hardcoded and thus should not be changed. Make sure to put these files in the project directory so that they can be found.

The class that implements this communication type is called `SSLSocketCommunicationSetup`.

SSL queue communication This is a special case of Queue communication that uses the SSL protocol during the communication with the JMS broker (server).

The way to construct an SSL queue differs from the way to construct an SSL socket. Unlike a socket construction, where there are unique classes for SSL sockets, in the JMS implementation the classes are the same. The only thing that determines the communication type is the URI given in the `ConnectionFactory` constructor. To create a plain and insecure communication use tcp://localhost:port uri; to create a secure connection that uses SSL protocol use **ssl**://localhost:port uri. In SCAPI's QueueCommunicationSetup class the connectionFactory is given as an argument

to the constructor, when the factory is already initialized with the URI. As a result, the choice of whether or not to use the SSL protocol is the user's responsibility.

We provide a concrete implementation of SSL queue communication that uses the ActiveMQ implementation, called `SSLActiveMQCommunicationSetup`. Like plain queue communication, the SSLActiveMQCommunicationSetup creates the factory inside the constructor and this way the user can avoid the factory construction. If a different SSL queue implementation is used, then the factory needs to be used, and the client and server certificates need to be loaded into the key store and trust store.

Note: In the SSL queue implementation, the other party of the SSL protocol is the JMS broker. Thus, the certificate that needs to be placed in the trust store is the certificate of the broker. In addition, this means that the broker server must either be trusted, or it must run on the same machine as one of the parties. Otherwise, the broker itself can run an man-in-the-middle attack.

SCAPI's `SSLActiveMQCommunicationSetup` implementation loads the scapiKeystore.jks and scapiCacerts.jks files mentioned above. It is the user's responsibility to put these files in the project library so that they can be found. On the ActiveMQ server side, there is a file called activemq.xml that manages the broker properties. In order to use the broker in SSL protocols one should add the following lines to this file:

```
    <sslContext>
            <sslContext keyStore="{path_to_broker_keystore}/{name_of_broker_keystore}.jks"
                                    keyStorePassword="{broker_keystore_password}"
                                    trustStore="{path_to_broker_truststore}/{name_of_broker_truststor
                                    trustStorePassword="{broker_truststore_password}"/>
</sslContext>

<transportConnectors>
    <transportConnector name="ssl" uri="ssl://0.0.0.0:61617?maximumConnections=1000&amp;wireFormat.ma
        <transportConnector name="https" uri="https://0.0.0.0:8443?maximumConnections=1000&amp;wireFo
        ...
</transportConnectors>
```

Note: In order to use ActiveMQ with the SSL protocol use the port 61617. This is unlike with plain queue communication where the port number is 61616.

We have specified the enabled SSL protocol to be TLSv1.2, and the enabled cipher suites to be TLS_ECDHE_ECDSA_WITH_AES_128_CBC_SHA256 and TLS_ECDHE_RSA_WITH_AES_128_CBC_SHA256. Moreover, we have specified the broker to use client authentication, and in addition to not use Nagle's algorithm. If you wish to enable Nagle's algorithm, then change the SSL tcpNoDelay property to false.

Multiparty communication

This is the communication layer for multiparty protocols, that provides a way to setup channels between all parties in a protocol and communicate between them.

Like the two party communication, this implementation improves the previous SCAPI multiparty communication in some aspects, including letting the user choose the channel type and the number of channels between each pair of parties, option to recover from communication failures and secure channels.

All the classes in the multiparty communication are in the `edu.biu.scapi.multiPartyComm` package.

The previous multiparty implementation in the `edu.biu.scapi.comm` package is from now on deprecated. We recommend not to use it since it will not be supported anymore.

The new multiparty implementation has two main parts:

- The first part is a communication that uses ActiveMQ queues in order to communicate between the parties. It uses a `TwoPartyCommunicationSetup` instance between each pair of parties. Thus, the classes that implement the queue multiparty communication are very slim since they delegate all functionality to the underlying two party instances.
- The second part is a communication that uses sockets in order to communicate between the parties. In this implementation, using the two party communication will be less effective. A Two party object listens to incoming connection on a given fixed port. If the multiparty communication will use two party instances, every two party instance will have the same port number (given to the multiparty comm) so all the objects will listen on the same port. This cannot be done in parallel since only one socket can be bound to each port at the same time. So the communication can be done only serially which is not efficient. In light of this, we chose to have a different, but very similar, implementation that listens to incoming connections from **all** parties. When receiving a connection, the listening thread will determine which party is calling and set the created socket to this party. The creation of the channels and the connecting step will be identical to the two party communication.

Both queues' and sockets' multiparty implementation has a plain communication and a secure communication channel. All the instructions (regarding the SSL protocol, ActiveMQ usage, etc) are the same as in the TwoPartyCommunicationSetup classes.

Setting up communication

There are several steps involved in setting up a communication channel between parties. Each one of them will be explained below:

Fetch the list of parties from a properties file

The first step towards obtaining communication services is to setup the connections between the different parties. Each party needs to run the setup process, at the end of which the established connections are obtained. The established connections are called channels. The list of parties and their addresses are usually obtained from a properties file. The format of the properties file depends on the concrete communication type.

The format of a socket properties file is as follows:

```
NumOfParties = 2
IP0 = <ip address of this application>
IP1 = <ip address of the other party>
Port0 = <port number of this application>
Port1 = <port number of party>
```

The format of a queue properties file is as follows:

```
URL = <URL of the JMS broker>
NumOfParties = 2
ID0 = <ID of this party>
ID1 = <ID of the other party>
```

Note: The property files and the classes that load them are not a necessary part of the communication. This is merely a more decoupled way to construct the PartyData objects that are needed in the communication setup phase; an application can also just construct these objects directly.

An example of the properties file used in socket communication (including SSL socket) called *SocketParties0.properties*, is as follows:

```
# A configuration file for the parties
```

```
NumOfParties = 2

IP0 = 132.71.122.117
IP1 = 132.71.122.117

Port0 = 8001
Port1 = 8000
```

An example of the properties file used in queue communication called *JMSParties0.properties* is as follows:

```
# A configuration file for the parties

URL = 132.71.122.117:61616

NumOfParties = 2

ID0 = 0
ID1 = 1
```

The socket and queue `LoadParties` classes are used for reading the properties file for socket and queue communication respectively:

```
import edu.biu.scapi.twoPartyComm.LoadSocketParties;
import edu.biu.scapi.twoPartyComm.SocketPartyData;

LoadSocketParties loadParties = new LoadSocketParties("SocketParties1.properties");
List<PartyData> listOfParties = loadParties.getPartiesList();
```

or

```
import edu.biu.scapi.twoPartyComm.LoadQueueParties;
import edu.biu.scapi.twoPartyComm.QueuePartyData;

LoadQueueParties loadParties = new LoadQueueParties("JmsParties1.properties");
List<PartyData> listOfParties = loadParties.getPartiesList();
```

Each party is represented by an instance of the `PartyData` class. A `List<PartyData>` object is required in the communication setup phase.

Setting up the actual communication

This step is different for two-party communication and for multiparty communication.

Two-Party communication

The `TwoPartyCommunicationSetup` interface is responsible for establishing secure communication to the other party. An application requesting from `TwoPartyCommunicationSetup` to prepare for communication needs to create the required concrete communicationSetup class: `SocketCommunicationSetup`, `SSLSocketCommunicationSetup` and `QueueCommunicationSetup`:

public class **`SocketCommunicationSetup`** implements TwoPartyCommunicationSetup, TimeoutObserver

public class **`SSLSocketCommunicationSetup`** extends SocketCommunicationSetup

public class **`QueueCommunicationSetup`** implements TwoPartyCommunicationSetup, TimeoutObserver

There is no specific class for SSL Queue communication because QueueCommunicationSetup can be used for SSL too. The actual communication protocol is determined in the `ConnectionFactory` constructor. The connectionFactory

is given in the QueueCommunicationSetup's constructor when it is already initialized. Thus, if SSL is to be used, then this needs to be specified in the factory creation, before calling the QueueCommunicationSetup constructor. As we have explained above, we have implemented a concrete class that uses the ActiveMQ implementation of JMS with SSL. It is called SSLActiveMQCommunicationSetup and will be explained later. The advantage of using this class is that the factory is not needed.

All concrete classes implement the org.apache.commons.exec.TimeoutObserver interface. This interface supplies a mechanism for notifying classes that a timeout has occurred.

In order to setup the actual communication, one of the following constructors is called (using the PartyData objects obtained from the LoadParties method previously used).

public void **`SocketCommunicationSetup`**(PartyData *me*, PartyData *party*)

Parameters

- **me** (*PartyData*) – Data of the current application.
- **party** (*PartyData*) – Data of the other application to communicate with.

public void **`SSLSocketCommunicationSetup`**(PartyData *me*, PartyData *party*, String *storePassword*)

Parameters

- **me** (*PartyData*) – Data of the current application.
- **party** (*PartyData*) – Data of the other application to communicate with.
- **storePassword** (*String*) – The password of the keystore and truststore.

public void **`SSLSocketCommunicationSetup`**(PartyData *me*, PartyData *party*, String *keyStoreName*, String *trustStoreName*, String *storePass*)

Parameters

- **me** (*PartyData*) – Data of the current application.
- **party** (*PartyData*) – Data of the other application to communicate with.
- **keyStoreName** (*String*) – Name of the key store file of this party.
- **trustStoreName** (*String*) – Name of the trust store file of this party.
- **storePassword** (*String*) – The password of the keystore and truststore.

public void **`QueueCommunicationSetup`**(ConnectionFactory *factory*, DestroyDestinationUtil *destroyer*, PartyData *me*, PartyData *party*)

Parameters

- **factory** (*ConnectionFactory*) – The class used to create the JMS connection. We get it from the user in order to be able to work with all types of connections.
- **destroyer** (*DestroyDestinationUtil*) – The class that delete the created destinations. Should match to the given factory.
- **me** (*PartyData*) – Data of the current application.
- **party** (*PartyData*) – Data of the other application to communicate with.

All constructors receive the data of the current and the other application. Note that the party data is different for socket and queue communication.

The `SSLSocketCommunicationSetup` constructor also receive the password of the keyStore and trustStore where the certificates are placed. This is needed for accessing the party's own private key. Also, there are constructors that get the key store and trust store files' names if the user does not want to use the default files.

The `QueueCommunicationSetup` constructor also receives the JMS factory and destroyer as parameters. We implement derived classes that uses the ActiveMQ implementation of JMS, called `ActiveMQCommunicationSetup` (for plain communication) and `SSLActiveMQCommunicationSetup` (for SSL communication). The constructors of these classes receive the parties' data and the ActiveMQ broker's URL and create both the factory and the `DestroyDestinationUtil`. Thus, the user can use this class instead of dealing with the factory and destroyer construction, i.e. instead of using `QueueCommunicationSetup` described above, one can call:

public void **`ActiveMQCommunicationSetup`** (String *url*, PartyData *me*, PartyData *party*)

Parameters

- **url** (*String*) – URL of the ActiveMQ broker.
- **me** (*PartyData*) – Data of the current application.
- **party** (*PartyData*) – Data of the other application to communicate with.

public void **`SSLActiveMQCommunicationSetup`** (String *url*, PartyData *me*, PartyData *party*, String *storePass*)

Parameters

- **url** (*String*) – URL of the ActiveMQ broker.
- **me** (*PartyData*) – Data of the current application.
- **party** (*PartyData*) – Data of the other application to communicate with.
- **storePass** (*String*) – The password of the keystore and truststore.

public void **`SSLActiveMQCommunicationSetup`** (String *url*, PartyData *me*, PartyData *party*, String *keyStoreName*, String *trustStoreName*, String *storePass*)

Parameters

- **url** (*String*) – URL of the ActiveMQ broker.
- **me** (*PartyData*) – Data of the current application.
- **party** (*PartyData*) – Data of the other application to communicate with.
- **keyStoreName** (*String*) – Name of the key store file of this party.
- **trustStoreName** (*String*) – Name of the trust store file of this party.
- **storePass** (*String*) – The password of the keystore and truststore.

After calling the constructor of the communication setup class, the application should call one of the `TwoPartyCommunicationSetup::prepareForCommunication` functions in order to establish connections:

public Map<String, Channel> **`prepareForCommunication`** (String[] *connectionsIds*, long *timeOut*)

Parameters

- **connectionsIds** (*String[]*) – The names of the required connections.
- **timeOut** (*long*) – A time-out (in milliseconds) specifying how long to wait for connections to be established.

Returns a map of the established channels.

public Map<String, Channel> **`prepareForCommunication`** (int *connectionsNum*, long *timeOut*)

Parameters

- **connectionsNum** (*int*) – The number of requested connections. The IDs of the created connection will be set with defaults values.

- **timeOut** (*long*) – A time-out (milliseconds) specifying how long to wait for connections to be established.

Returns a map of the established channels.

In both of the above functions, the user can generate one or more connections between the parties. The channels are connected using a **single port** for each application, specified in the PartyData objects given in the constructor. The first function is used when the user wishes to provide the name of each connection. The second function is used if the user wishes these "names" to be generated automatically. In this case, the name of a channel is actually the index of the channel. That is, the first created channel is named "1", the second is "2" and so on. These functions can be called several times. The class internally stores the number of created channels so that the next index can be given, when using the second function.

By default, Nagle's algorithm is disabled since this has much better performance for cryptographic algorithms. In order to change the default value, call the `enableNagle()` function in the socket implementations. In the queue implementations usage of Nagle's algorithm can be changed only on construction time so we've added a constructor with `boolean enableNagle` to let the user determine if Nagle's algorithm should be used or not.

Here is an example on how to use the `SocketCommunicationSetup` class:

```
import java.util.List;
import java.util.Map;

import edu.biu.scapi.exceptions.DuplicatePartyException;
import edu.biu.scapi.twoPartyComm.LoadSocketParties;
import edu.biu.scapi.twoPartyComm.PartyData;
import edu.biu.scapi.twoPartyComm.SocketCommunicationSetup;
import edu.biu.scapi.twoPartyComm.SocketPartyData;
import edu.biu.scapi.twoPartyComm.TwoPartyCommunicationSetup;

//Prepare the parties list.
LoadSocketParties loadParties = new LoadSocketParties("SocketParties1.properties");
List<PartyData> listOfParties = loadParties.getPartiesList();

TwoPartyCommunicationSetup commSetup = new SocketCommunicationSetup(listOfParties.get(0), listOfParti

//Call the prepareForCommunication function to establish one connection within 2000000 milliseconds.
Map<String, Channel> connections = commSetup.prepareForCommunication(1, 2000000);

//Return the channel to the calling application. There is only one created channel.
return (Channel) connections.values().toArray()[0];
```

In order to use the `SSLSocketCommunicationSetup` class one should add the password parameter to the constructor:

```
import java.util.List;
import java.util.Map;

import edu.biu.scapi.exceptions.DuplicatePartyException;
import edu.biu.scapi.twoPartyComm.LoadSocketParties;
import edu.biu.scapi.twoPartyComm.PartyData;
import edu.biu.scapi.twoPartyComm.SSLSocketCommunicationSetup;
import edu.biu.scapi.twoPartyComm.TwoPartyCommunicationSetup;

//Prepare the parties list.
LoadSocketParties loadParties = new LoadSocketParties("SocketParties1.properties");
    List<PartyData> listOfParties = loadParties.getPartiesList();

    TwoPartyCommunicationSetup commSetup = new SSLSocketCommunicationSetup(listOfParties.get(0), list
```

```
    //Call the prepareForCommunication function to establish one connection within 2000000 millisecon
    Map<String, Channel> connections = commSetup.prepareForCommunication(1, 2000000);

    //Return the channel with the other party. There was only one channel created.
    return (Channel) connections.values().toArray()[0];
```

Here is an example of how to use the `ActiveMQCommunicationSetup` class:

```
import java.util.List;
import java.util.Map;

import edu.biu.scapi.exceptions.DuplicatePartyException;
import edu.biu.scapi.twoPartyComm.LoadQueueParties;
import edu.biu.scapi.twoPartyComm.PartyData;
import edu.biu.scapi.twoPartyComm.ActiveMQCommunicationSetup;
import edu.biu.scapi.twoPartyComm.TwoPartyCommunicationSetup;

//Prepare the parties list.
LoadQueueParties loadParties = new LoadQueueParties("JmsParties1.properties");
List<PartyData> listOfParties = loadParties.getPartiesList();

TwoPartyCommunicationSetup commSetup = new ActiveMQCommunicationSetup(loadParties.getURL(), listOfPar

//Call the prepareForCommunication function to establish two connections within 2000000 milliseconds
Map<String, Channel> connections = commSetup.prepareForCommunication(2, 2000000);

//Return the channels to the calling application.
return connections.values().toArray();
```

And an example to `SSLActiveMQCommunicationSetup` class:

```
    import java.util.List;
import java.util.Map;

import edu.biu.scapi.exceptions.DuplicatePartyException;
import edu.biu.scapi.twoPartyComm.LoadQueueParties;
import edu.biu.scapi.twoPartyComm.PartyData;
import edu.biu.scapi.twoPartyComm.SSLActiveMQCommunicationSetup;
import edu.biu.scapi.twoPartyComm.TwoPartyCommunicationSetup;

    //Prepare the parties list.
    LoadQueueParties loadParties = new LoadQueueParties("JmsParties1.properties");
    List<PartyData> listOfParties = loadParties.getPartiesList();

    TwoPartyCommunicationSetup commSetup = new SSLActiveMQCommunicationSetup(loadParties.getURL(), li

    Map<String, Channel> connections = commSetup.prepareForCommunication(1, 2000000);

    //Return the channels to the calling application.
    return connections.values().toArray();
```

Multiparty communication

The `MultipartyCommunicationSetup` interface is responsible for establishing secure communication between the current running application to each other party in the protocol. An application requesting from `MultipartyCommunicationSetup` to prepare for communication needs to create the required concrete multiparty communicationSetup class: `SocketMultipartyCommunicationSetup`,

`SSLSocketMultipartyCommunicationSetup`, `ActiveMQMultipartyCommunicationSetup` and `SSLActiveMQMultipartyCommunicationSetup`:

public class **`SocketMultipartyCommunicationSetup`** implements MultipartyCommunicationSetup, TimeoutObserver

public class **`SSLSocketMultipartyCommunicationSetup`** extends SocketMultipartyCommunicationSetup

public class **`ActiveMQMultipartyCommunicationSetup`** implements MultipartyCommunicationSetup

public class **`SSLActiveMQMultipartyCommunicationSetup`** extends ActiveMQMultipartyCommunicationSetup

Here, unlike the two party implementation there is no abstract class for queue communication. As mentioned above, the queue multiparty communication uses two party instances between the current running application and any other party in the protocol. In order to create the underling two party objects, one should know exactly which specific class he should create. This specific two party object fixed the multiparty implementation and that is the reason it cannot be abstract.

The socket implementations implement the org.apache.commons.exec.TimeoutObserver interface. This interface supplies a mechanism for notifying classes that a timeout has occurred. The queue implementations should not implementat this interface since they use the two party queue implementation that implements the TimeoutObserver interface.

In order to setup the actual communication, one of the following constructors is called (using the PartyData list obtained from the LoadParties method previously used).

public void **`SocketMultipartyCommunicationSetup`**(List<PartyData> *parties*)

Parameters

- **parties** (*List<PartyData>*) – Data of the current application.

public void **`SSLSocketMultipartyCommunicationSetup`**(List<PartyData> *parties*, String *storePass*)

Parameters

- **parties** (*List<PartyData>*) – Data of the current application.
- **storePass** (*String*) – The password of the keystore and truststore.

public void **`SSLSocketMultipartyCommunicationSetup`**(List<PartyData> *parties*, String *keyStoreName*, String *trustStoreName*, String *storePass*)

Parameters

- **parties** (*List<PartyData>*) – Data of the current application.
- **keyStoreName** (*String*) – Name of the key store file of this party.
- **trustStoreName** (*String*) – Name of the trust store file of this party.
- **storePass** (*String*) – The password of the keystore and truststore.

public void **`ActiveMQMultipartyCommunicationSetup`**(String *url*, List<PartyData> *parties*)

Parameters

- **url** (*String*) – URL of the ActiveMQ broker.
- **parties** (*List<PartyData>*) – Data of the current application.

public void **`SSLActiveMQMultipartyCommunicationSetup`**(String *url*, List<PartyData> *parties*, String *storePass*)

Parameters

- **url** (*String*) – URL of the ActiveMQ broker.
- **parties** (*List<PartyData>*) – Data of the current application.

- **storePass** (*String*) – The password of the keystore and truststore.

public void **SSLActiveMQMultipartyCommunicationSetup**(String *url*, List<PartyData> *parties*, String *keyStoreName*, String *trustStoreName*, String *storePass*)

Parameters

- **url** (*String*) – URL of the ActiveMQ broker.
- **parties** (*List<PartyData>*) – Data of the current application.
- **keyStoreName** (*String*) – Name of the key store file of this party.
- **trustStoreName** (*String*) – Name of the trust store file of this party.
- **storePass** (*String*) – The password of the keystore and truststore.

All constructors receive the data of all the parties participate in the protocol, while the first party in the list represents the current running party. Note that the party data objects are different for socket and queue communication.

As in the two parties communication, the secure multiparty classes also receive in the constructor the password of the keyStore and trustStore where the certificates are placed, and there are constructors that get the key store and trust store files' names.

After calling the constructor of the communication setup class, the application should call the `MultipartyCommunicationSetup::prepareForCommunication` function in order to establish connections:

public Map<PartyData, Map<String, Channel>> **prepareForCommunication**(Map<PartyData, Object> *connectionsPerParty*, long *timeOut*)

Parameters

- **connectionsPerParty** (*Map<PartyData,Object>*) – provides the amount of connections or the names of connections that should be created between the current application and other parties in the protocol.
- **timeOut** (*long*) – A time-out (in milliseconds) specifying how long to wait for connections to be established.

Returns a map contains the connected channels. The key to the map is a PartyData object (represents a party participates in the protocol) and the value is the created connections to this party.

Notice that in the two party implementation there are two prepareForCommunication functions. One gets the **number** of requested connections and one gets the **names** of the requested connections. Here, there is only one function that can get both things, since the parameter type is `Map<PartyData, Object>` and object can be anything. This is done that way because of technical reasons, since for java `Map<PartyData, Integer>` and `Map<PartyData, string[]>` are the same thing and therefore java does not allow to split that into two different functions.

As in the two party communication, the user can generate one or more connections between the parties. The channels are connected using a **single port** for each application, specified in the first PartyData object in the given parties list.

Here is an example on how to use the `SocketMultipartyCommunicationSetup` class:

```
import java.util.List;
import java.util.Map;

    import edu.biu.scapi.comm.Channel;
    import edu.biu.scapi.comm.multiPartyComm.MultipartyCommunicationSetup;
    import edu.biu.scapi.comm.multiPartyComm.SocketMultipartyCommunicationSetup;
    import edu.biu.scapi.comm.twoPartyComm.LoadSocketParties;
    import edu.biu.scapi.comm.twoPartyComm.PartyData;
```

```
     //Prepare the parties list.
     LoadSocketParties loadParties = new LoadSocketParties("MultiPartySocketParties1.properties");

List<PartyData> listOfParties = loadParties.getPartiesList();

    //Create the communication setup class.
    MultipartyCommunicationSetup commSetup = new SocketMultipartyCommunicationSetup(listOfParties);

    //Request two chanels between me and each other party.
    HashMap<PartyData, Object> connectionsPerParty = new HashMap<PartyData, Object>();

    connectionsPerParty.put(listOfParties.get(1), 2);
    connectionsPerParty.put(listOfParties.get(2), 2);

    //Call the prepareForCommunication function to establish the connections within 2000000 millisec
    Map<PartyData, Map<String, Channel>> connections = commSetup.prepareForCommunication(connections

    //Returns the channels to the other parties.
    return connections;
```

In order to use the `SSLSocketMultipartyCommunicationSetup` class one should add the key store name, trust store name and password to the constructor:

```
import java.util.List;
import java.util.Map;

    import edu.biu.scapi.comm.Channel;
    import edu.biu.scapi.comm.multiPartyComm.MultipartyCommunicationSetup;
    import edu.biu.scapi.comm.multiPartyComm.SSLSocketMultipartyCommunicationSetup;
    import edu.biu.scapi.comm.twoPartyComm.LoadSocketParties;
    import edu.biu.scapi.comm.twoPartyComm.PartyData;

//Prepare the parties list.
LoadSocketParties loadParties = new LoadSocketParties("SocketParties1.properties");
    List<PartyData> listOfParties = loadParties.getPartiesList();

    //Create the communication setup class.
    MultipartyCommunicationSetup commSetup = new SSLSocketMultipartyCommunicationSetup(listOfParties,

    //Request two chanels between me and each other party.
    HashMap<PartyData, Object> connectionsPerParty = new HashMap<PartyData, Object>();
    connectionsPerParty.put(listOfParties.get(1), 2);
    connectionsPerParty.put(listOfParties.get(2), 2);

    //Call the prepareForCommunication function to establish the connections within 2000000 millisec
    Map<PartyData, Map<String, Channel>> connections = commSetup.prepareForCommunication(connections

    //Returns the channels to the other parties.
    return connections;
```

Here is an example of how to use the `ActiveMQMultipartyCommunicationSetup` class:

```
import java.util.List;
import java.util.Map;

    import edu.biu.scapi.comm.Channel;
import edu.biu.scapi.exceptions.DuplicatePartyException;
import edu.biu.scapi.twoPartyComm.LoadQueueParties;
```

```
import edu.biu.scapi.twoPartyComm.PartyData;
import edu.biu.scapi.multiPartyComm.ActiveMQMultiPartyCommunicationSetup;
import edu.biu.scapi.multiPartyComm.MultipartyCommunicationSetup;

    //Prepare the parties list.
    LoadQueueParties loadParties = new LoadQueueParties("MultiPartyQueueParties1.properties");
List<PartyData> listOfParties = loadParties.getPartiesList();

    //Create the communication setup class.
    MultipartyCommunicationSetup commSetup = new ActiveMQMultipartyCommunicationSetup(loadParties.get

    //Request two chanels between me and each other party.
    HashMap<PartyData, Object> connectionsPerParty = new HashMap<PartyData, Object>();
    connectionsPerParty.put(listOfParties.get(1), 2);
    connectionsPerParty.put(listOfParties.get(2), 2);

    //Call the prepareForCommunication function to establish the connections within 2000000 millisec
    Map<PartyData, Map<String, Channel>> connections = commSetup.prepareForCommunication(connectionsP

    //Returns the channels to the other parties.
    return connections;
```

And an example to `SSLActiveMQMultipartyCommunicationSetup` class:

```
    import java.util.List;
import java.util.Map;

    import edu.biu.scapi.comm.Channel;
import edu.biu.scapi.exceptions.DuplicatePartyException;
import edu.biu.scapi.twoPartyComm.LoadQueueParties;
import edu.biu.scapi.twoPartyComm.PartyData;
import edu.biu.scapi.multiPartyComm.ActiveMQMultiPartyCommunicationSetup;
import edu.biu.scapi.multiPartyComm.MultipartyCommunicationSetup;

    //Prepare the parties list.
    LoadQueueParties loadParties = new LoadQueueParties("MultiPartySSLQueueParties1.properties");
    List<PartyData> listOfParties = loadParties.getPartiesList();

    //Create the communication setup class.
    MultipartyCommunicationSetup commSetup = new SSLActiveMQMultipartyCommunicationSetup(loadParties

    //Request two chanels between me and each other party.
    HashMap<PartyData, Object> connectionsPerParty = new HashMap<PartyData, Object>();
    connectionsPerParty.put(listOfParties.get(1), 2);
    connectionsPerParty.put(listOfParties.get(2), 2);

    //Call the prepareForCommunication function to establish the connections within 2000000 millisec
    Map<PartyData, Map<String, Channel>> connections = commSetup.prepareForCommunication(connectionsP

    //Returns the channels to the other parties.
    return connections;
```

Verifying that the connections were established

In two-party protocols, success means that all requested channels have been established between the parties. The output from the prepareForCommunication function is a map containing the established channels.

In multi-party protocols, different computations may require different types of success when checking the connections

between all the parties that were supposed to participate. Some protocols may need to make sure that absolutely all parties participating in it have established connections one with another; other protocols may need only a certain percentage of connections to have succeeded. In the current multiparty communication setup implementation, we implement success as all requested channels have been established. In the future we may support different levels of success.

In case a timeout has occurred before all requested channels have been connected, all connected channels will be closed and a `ScapiRuntimeException` will be thrown.

Closing the connection

The application is responsible for closing the communicationSetup class that creates the channels. This is because this class may contain some members that need to be closed. For example, the `QueueCommunicationSetup` has the JMS Connection object as a class member, and this must be closed at the end of the setup.

Needless to say, the application must also close each created channel when it is no longer needed.

Using an established connection

A connection is represented by the `Channel` interface. Once a channel is established, we can `send()` and `receive()` data between parties.

public interface **`Channel`**

public void **`send`**(Serializable *data*)
Sends a message *msg* to the other party, *msg* must be a `Serializable` object.

public Serializable **`receive`**()
Receives a message from the channel.

Returns Returns the received message as `Serializable`. Conversion to the right type is the responsiblity of the caller.

public void **`close`**()
Closes the connection.

public boolean **`isClosed`**()

Returns `true` if the connection is closed, `false` otherwise.

Security of the connection

Note: This section is relevant for all channel types **except the SSLChannel**. SSL channels do the encryption and authentication in the SSL protocol and therefore do not need to be wrapped with SCAPI's encrypted and/or authenticated channels. The methods described here are useful for anyone who does not wish to setup certificates and would rather work with pre-shared secrets.

A channel can have Plain, Encrypted or Authenticated security level, depending on the requirements of the application. The type of security set by *CommunicationSetup* classes is *Plain* security, and is represented by the classes `PlainTCPChannel`, `PlainTCPSocketChannel` and `QueueChannel`. In case a higher security standard is needed, the user must set it manually, by using the decorator classes `AuthenticatedChannel` and `EncryptedChannel`.

Plain Channel

Plain security is the default type of security set by the CommunicationSetup classes. The `PlainTCPChannel`, `PlainTCPSocketChannel` and `QueueChannel` classes are plain channels by default and so do not provide authentication or encryption. The plain channel types are as follows:

public class **`PlainTCPChannel`** extends Channel

public class **`PlainTCPSocketChannel`** extends Channel

public class **`QueueChannel`** extends Channel

AuthenticatedChannel

public class **`AuthenticatedChannel`** extends ChannelDecorator

This channel ensures `UnlimitedTimes` security level, meaning that there is no a priori bound on the number of messages that can be MACed. The owner of the channel is responsible for setting the MAC algorithm to use and making sure that the MAC is initialized with a suitable key. Then, every message sent via this channel is authenticated using the underlying MAC algorithm and every message received is verified by it.

The user needs not worry about any of the authentication and verification tasks as they are carried out automatically by the channel. Note that plain objects are passed to the channel and received from the channel and the processes of MACing and verifying the MAC are carried out inside the channel, invisible to the user.

public **`AuthenticatedChannel`** (Channel *channel*, Mac *mac*)

This public constructor can be used by anyone holding a channel that is connected. Such a channel can be obtained by running the prepareForCommunication function of `CommunicationSetup` which returns a set of already connected channels.

Parameters

- **channel** – an already connected channel
- **mac** – the MAC algorithm required to authenticate the messages sent by this channel

Throws

- **SecurityLevelException** – if the MAC algorithm passed is not UnlimitedTimes-secure

public void **`setKey`** (SecretKey *key*)

Sets the key of the underlying MAC algorithm. This function must be called before sending or receiving messages if the MAC algorithm passed to this channel had not been set with a key yet. The key can be set indefinite number of times depending on the needs of the application.

Parameters

- **key** – a suitable SecretKey

Throws

- **InvalidKeyException** – if the given key does not match the underlying MAC algorithm.

Example of Usage:

We assume in this example that `ch` is an already established channel as we have already shown how to setup a channel using CommunicationSetup. We stress that this is the code for one party, but both parties must decorate their respective channels with `AuthenticatedChannel` in order for it to work.

```
import java.security.InvalidKeyException;

import javax.crypto.SecretKey;
import javax.crypto.spec.SecretKeySpec;

import edu.biu.scapi.comm.*;
import edu.biu.scapi.midLayer.symmetricCrypto.mac.Mac;
import edu.biu.scapi.tools.Factories.*;
import edu.biu.scapi.exceptions.*;

public AuthenticatedChannel createAuthenticatedChannel(Channel ch) {
    Mac mac = null;

        mac = new ScCbcMacPrepending(new BcAES());

    ///You could generate the key here and then somehow send it to the other party so the other party
        //SecretKey macKey = SecretKeyGeneratorUtil.generateKey("AES");
        //Instead, we use a secretKey that has already been agreed upon by both parties:
            byte[] aesFixedKey = new byte[]{-61, -19, 106, -97, 106, 40, 52, -64, -115, -19, -87, -67
        SecretKey key = new SecretKeySpec(aesFixedKey, "AES");

    try {
        mac.setKey(key);
    } catch (InvalidKeyException e) {
        e.printStackTrace();
    }

    //Decorate the Plain TCP Channel with the authentication
    AuthenticatedChannel authenChannel = null;
    try {
        authenChannel = new AuthenticatedChannel(ch, mac);
    } catch (SecurityLevelException e) {
        // This exception will not happen since we chose a Mac that meets the Security Level require
        e.printStackTrace();
    }

    return authenChannel;
}
```

After converting the channel to an authenticated channel, we can simply call `send()` and `receive()` again in the same manner as before, only this time the messages are authenticated for us.

EncryptedChannel

public class **`EncryptedChannel`** extends ChannelDecorator

This channel ensures `CPA` security level (security in the presence of chosen-plaintext attacks). The owner of the channel is responsible for setting the encryption scheme to use and making sure that the encryption scheme is initialized with a suitable key. Then, every message sent via this channel is encrypted and decrypted using the underlying encryption scheme. As with an authenticated channel, the encryption and decryption are carried out invisibly to the user (who sends and receives plain objects).

We remark that in the setting of secure computation, encrypted but not authenticated channels should typically not be used.

public **`EncryptedChannel`** (Channel *channel*, SymmetricEnc *encScheme*)

This public constructor can be used by anyone holding a channel that is connected. Such a channel can be obtained by running the prepareForCommunications function of `CommunicationSetup` which returns a set

of already connected channels.

The function creates a new EncryptedChannel that wraps the already connected channel mentioned above. The encryption scheme must be CPA-secure, otherwise an exception is thrown. The encryption scheme does not need to be initialized with a key at this moment (even though it can be), but before sending or receiving a message over this channel the relevant secret key must be set with setKey().

Parameters

- **channel** – an already connected channel
- **encScheme** – a symmetric encryption scheme that is CPA-secure.

Throws

- **SecurityLevelException** – if the encryption scheme is not CPA-secure

public void **setKey**(SecretKey *key*)

Sets the key of the underlying encryption scheme. This function must be called before sending or receiving messages if the encryption scheme passed to this channel had not been set with a key yet. The key can be set indefinite number of times depending on the needs of the application.

Parameters

- **key** – a suitable SecretKey

Throws

- **InvalidKeyException** – if the given key does not match the underlying MAC algorithm.

Example of Usage

This example is very similar to the previous one. As before we only show how to decorate the established channel after `CommunicationSetup` is called.

```
import java.io.IOException;
import java.security.InvalidKeyException;

import javax.crypto.SecretKey;
import javax.crypto.spec.SecretKeySpec;

import edu.biu.scapi.comm.Channel;
import edu.biu.scapi.comm.EncryptedChannel;
import edu.biu.scapi.exceptions.SecurityLevelException;
import edu.biu.scapi.midLayer.symmetricCrypto.encryption.ScCTREncRandomIV;
import edu.biu.scapi.primitives.prf.AES;
import edu.biu.scapi.primitives.prf.bc.BcAES;

public EncryptedChannel createEncryptedChannel(Channel ch) {
    ScCTREncRandomIV enc = null;
    try {
        // first we generate the secret key for the PRP that is used by the encryption object.

        // You could generate the key here and then somehow send it to the other party so the other p
        // SecretKey encKey = SecretKeyGeneratorUtil.generateKey("AES");
        //Instead, we use a secretKey that has already been agreed upon by both parties:
        byte[] aesFixedKey = new byte[]{-61, -19, 106, -97, 106, 40, 52, -64, -115, -19, -87, -67, 98
        SecretKey encKey = new SecretKeySpec(aesFixedKey, "AES");

        // now, we initialize the PRP, set the key, and then initialize the encryption object
        AES aes = new BcAES();
```

```
            aes.setKey(encKey);
            enc = new ScCTREncRandomIV(aes);

        } catch (InvalidKeyException e) {
            e.printStackTrace();
        }

        //Decorate the Plain TCP Channel with the EncryptedChannel class
        EncryptedChannel encChannel = null;
        try {
            encChannel = new EncryptedChannel(ch, enc);
        } catch (SecurityLevelException e) {
            // This exception will not happen since we chose an encryption scheme that meets the Security
            e.printStackTrace();
        }

        return encChannel;
    }
```

Encrypted and Authenticated Channel

We now provide an example of both encrypted and authenticated communication. This example is very similar to the previous ones. When using encryption and authentication in the correct order (encrypt-then-authenticate), authenticated encryption security is obtained (which is in particular CCA secure).

```
import java.io.IOException;
import java.security.InvalidKeyException;

import javax.crypto.SecretKey;
import javax.crypto.spec.SecretKeySpec;

import edu.biu.scapi.comm.Channel;
import edu.biu.scapi.comm.EncryptedChannel;
import edu.biu.scapi.exceptions.SecurityLevelException;
import edu.biu.scapi.midLayer.symmetricCrypto.encryption.ScCTREncRandomIV;
import edu.biu.scapi.midLayer.symmetricCrypto.encryption.ScEncryptThenMac;
import edu.biu.scapi.midLayer.symmetricCrypto.mac.ScCbcMacPrepending;
import edu.biu.scapi.primitives.prf.AES;
import edu.biu.scapi.primitives.prf.bc.BcAES;

public EncryptedChannel createSecureChannel(Channel ch) {
    ScCTREncRandomIV enc = null;
    ScCbcMacPrepending cbcMac = null;
    try {
        // first, we set the encryption object

        // You could generate the key here and then somehow send it to the other party so the other p
        // SecretKey encKey = SecretKeyGeneratorUtil.generateKey("AES");
        //Instead, we use a secretKey that has already been agreed upon by both parties:
        byte[] aesFixedKey = new byte[]{-61, -19, 106, -97, 106, 40, 52, -64, -115, -19, -87, -67, 98
        SecretKey aesKey = new SecretKeySpec(aesFixedKey, "AES");

        AES encryptAes = new BcAES();
        encryptAes.setKey(aesKey);

        // create encryption object from PRP
        enc = new ScCTREncRandomIV(encryptAes);
```

```
        // second, we create the mac object
        AES macAes = new BcAES();

        macAes.setKey(aesKey);
        // create Mac object from PRP
        cbcMac = new ScCbcMacPrepending(macAes);

    } catch (InvalidKeyException e) {
        e.printStackTrace();
    }

    //Create the encrypt-then-mac object using encryption and authentication objects.
    ScEncryptThenMac encThenMac = null;
    encThenMac = new ScEncryptThenMac(enc, cbcMac);

    //Decorate the Plain TCP Channel with the authentication
    EncryptedChannel secureChannel = null;
    try {
        secureChannel = new EncryptedChannel(ch, encThenMac);
    } catch (SecurityLevelException e) {
        // This exception will not happen since we chose a Mac that meets the Security Level require
        e.printStackTrace();
    }

    return secureChannel;
}
```

Multiparty communication

The multiparty communication layer will be updated soon to be based on the two-party communication layer. Meanwhile, the description below is for the old implementation which will soon be deprecated.

Fetch the list of parties from a properties file

The first thing that needs to be done to obtain communication services is to setup the connections between the different parties. Each party needs to run the setup process at the end of which the established connections are obtained. The established connections are called *channels*. The list of parties and their addresses are usually obtained from a Properties file. For example, here is a properties file called *Parties0.properties*:

```
# A configuration file for the parties

NumOfParties = 2

IP0 = 127.0.0.1
IP1 = 127.0.0.1

Port0 = 8001
Port1 = 8000
```

In order to read this file, we can use the `LoadParties` class:

```
import edu.biu.scapi.comm.Party;
import edu.biu.scapi.comm.LoadParties;
```

```
LoadParties loadParties = new LoadParties("Parties0.properties");
List<Party> listOfParties = loadParties.getPartiesList();
```

Each party is represented by an instance of the `Party` class. A `List<Party>` object is required in the multiParty communication setup phase.

Setup communication to other parties

The `CommunicationSetup` Class is responsible for establishing secure communication to other parties. An application requesting from `CommunicationSetup` to prepare for communication needs to call the `CommunicationSetup::prepareForCommunication()` function:

public class **`CommunicationSetup`** implements TimeoutObserver

CommunicationSetup implements the org.apache.commons.exec.TimeoutObserver interface. This interface supplies a mechanism for notifying classes that a timeout has arrived.

Map<InetSocketAddress, Channel> **`prepareForCommunication`**(List<Party> *listOfParties*, ConnectivitySuccessVerifier *successLevel*, long *timeOut*, boolean *enableNagle*)

Parameters

- **listOfParties** (*List<Party>*) – The list of parties to connect to. As a convention, we will set the first party in the list to be the requesting party, that is, the party represented by the application.
- **successLevel** (*ConnectivitySuccessVerifier*) – The type of multi party connecting success required.
- **timeOut** (*long*) – A time-out (in milliseconds) specifying how long to wait for connections to be established and secured.
- **enableNagle** (*boolean*) – Whether or not *Nagle's algorithm <http://en.wikipedia.org/wiki/Nagle's_algorithm>* can be enabled.

Returns a map of the established channels.

Here is an example on how to use the *CommunicationSetup* class, we leave the discussion about the *ConnectivitySuccessVerifier* instance to the next section.

```
import java.net.InetSocketAddress;
import java.util.List;
import java.util.Map;

import edu.biu.scapi.comm.Party;
import edu.biu.scapi.comm.LoadParties;

import edu.biu.scapi.comm.Channel;
import edu.biu.scapi.comm.CommunicationSetup;

import edu.biu.scapi.comm.ConnectivitySuccessVerifier;
import edu.biu.scapi.comm.NaiveSuccess;

//Prepare the parties list.
LoadParties loadParties = new LoadParties("Parties0.properties");
List<Party> listOfParties = loadParties.getPartiesList();

//Create the communication setup.
CommunicationSetup commSetup = new CommunicationSetup();
```

```
//Choose the naive connectivity success algorithm.
ConnectivitySuccessVerifier naive = new NaiveSuccess();

long timeoutInMs = 60000; //The maximum amount of time we are willing to wait to set a connection.

Map<InetSocketAddress, Channel> map = commSetup.prepareForCommunication(listOfParties, naive, timeout

// prepareForCommunication() returns a map with all the established channels,
// we return only the first one since this code assumes the two-party case.
return map.values().iterator().next();
```

Verifying that the connections were established

Different Multi-parties computations may require different types of success when checking the connections between all the parties that were supposed to participate. Some protocols may need to make sure that absolutely all parties participating in it have established connections one with another; other protocols may need only a certain percentage of connections to have succeeded. There are many possibilities and each one of them is represented by a class implementing the `ConnectivitySuccessVerifier` interface. The different classes that implement this interface will run different algorithms to verify the level of success of the connections. It is up to the user of the `CommunicationSetup` class to choose the relevant level and pass it on to the `CommunicationSetup` upon calling the `prepareForCommuncation` function.

public interface **`ConnectivitySuccessVerifier`**

public boolean **`hasSucceded`**(EstablishedConnections *estCon*, List<Party> *originalListOfParties*)

This function gets the information about the established connections as input and the original list of parties, then it runs a certain algorithm (determined by the implementing class), and it returns true or false according to the level of connectivity checked by the implementing algorithm.

Parameters

- **estCon** – the actual established connections
- **originalListOfParties** – the original list of parties to connect to

Returns `true` if the level of connectivity was reached (depends on implementing algorithm) and `false` otherwise.

Naive

public class **`NaiveSuccess`** implements ConnectivitySuccessVerifier

NaiveSuccess does not actually check the connections but rather always returns true. It can be used when there is no need to verify any level of success in establishing the connections.

Clique

public class **`CliqueSuccess`** implements ConnectivitySuccessVerifier

For future implementation.

•Check if connected to all parties in original list.

•Ask every party if they are connected to all parties in their list.

•If all answers are true, return true,

•Else, return false.

SecureClique
public class **`SecureCliqueSuccess`** implements ConnectivitySuccessVerifier

For future implementation.

- Check if connected to all parties in original list.
- Ask every party if they are connected to all parties in their list. USE SECURE BROADCAST. DO NOT TRUST THE OTHER PARTIES.
- If all answers are true, return true,
- Else, return false.

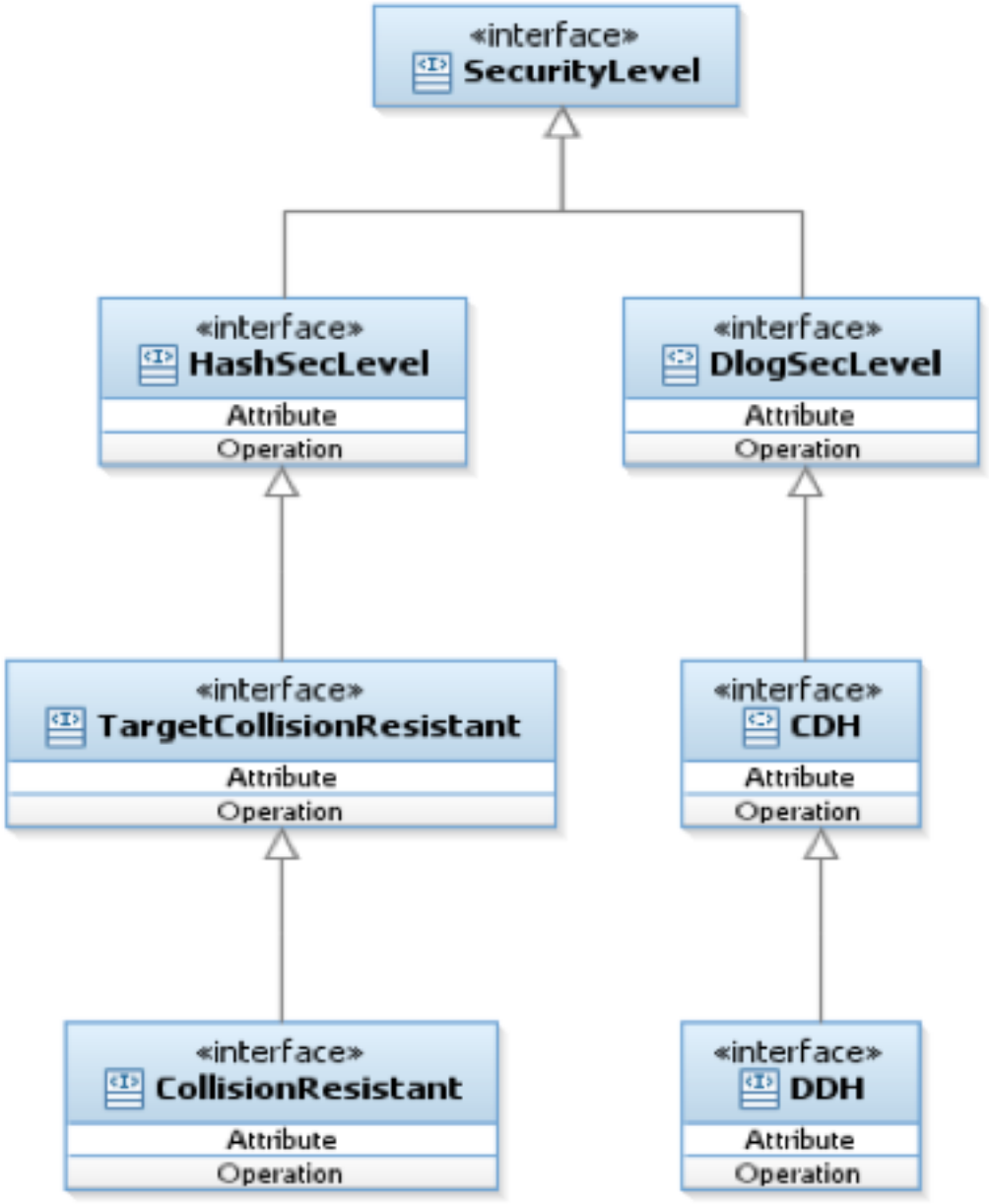
Layer 1: Basic Primitives

Security Levels

In many cases, a cryptographic primitive is not just "secure" or "insecure". Rather, it may meet some notion of security and not another. A classic example is encryption, where a scheme can be secure in the presence of eavesdropping adversaries (EAV), in the presence of chosen-plaintext attacks (CPA) or in the presence of chosen-ciphertext attacks (CCA). These three levels of security also form a hierarchy (any scheme that is secure in the presence of chosen-ciphertext attacks, is secure against chosen-plaintext attacks and so on). The choice of which level of security to require, depends on the application. We remark that it is not always wise to take the "most secure" scheme since this sometimes comes with a performance penalty. In addition, in some cases (like in commitments), the security levels are non-comparable.

Protocols that by definition need to work with primitives that hold a specific security level are responsible for checking that the primitives meet the security level requirements. For example, an encryption scheme that is secure under DDH should check that it receives a Dlog Group with security level `DDH`.

The library therefore includes a hierarchy of security level interfaces; specifically in this layer for `DlogGroup` and `CryptographicHash` families. These interfaces have no methods and are only marker interfaces. Each concrete class that is based on any security level should implement the relevant interface, to declare itself as secure as the marker interface.



Cryptographic Hash

A **cryptographic hash** function is a deterministic procedure that takes an arbitrary block of data and returns a fixed-size bit string, the (cryptographic) hash value. There are two main levels of security that we will consider here:

- **target collision resistance:** meaning that given x it is hard to find y such that $H(y) = H(x)$.
- **collision resistance:** meaning that it is hard to find any x and y such that $H(x) = H(y)$.

Note: We do not include **preimage resistance** since cryptographically this is just a one-way function.

Contents

The `CryptographicHash` interface

The user may request to pass partial data to the hash and only after some iterations to obtain the hash of all the data. This is done by calling the function `update()`. After the user is done updating the data it can call the `hashFinal()` to obtain the hash output.

void **`update`**(byte[] *in*, int *inOffset*, int *inLen*)
Adds the byte array to the existing msg to hash.

Parameters

- **in** – input byte array
- **inOffset** – the offset within the byte array
- **inLen** – the length. The number of bytes to take after the offset

void **`hashFinal`**(byte[] *out*, int *outOffset*)
Completes the hash computation.

Parameters

- **out** – the output in byte array
- **outOffset** – the offset which to put the result bytes from

Usage

The best way to use CryptographicHash is via the CryptographicHashFactory factory class.

```
//create an input array in and an output array out
...

//call the CryptographicHashFactory.
CryptographicHash hash = CryptographicHashFactory.getInstance().getObject("SHA-1");

//call the update function in the Hash interface.
hash.update(in, 0, in.length);

//get the result of hashing the updated input.
hash.hashFinal(out, 0);
```

Supported Hash Types

In this section we present possible keys to the `CryptographicHashFactory`.

Default keys: (point to the Crypto++ implementation)

Key	Class
SHA-1	CryptoPP
SHA-224	CryptoPP
SHA-256	CryptoPP
SHA-384	CryptoPP
SHA-512	CryptoPP

The BouncyCastle implementation:

Key	Class
BCSHA-1	edu.biu.scapi.primitives.hash.bc.BcSHA1
BCSHA-224	edu.biu.scapi.primitives.hash.bc.BcSHA224
BCSHA-256	edu.biu.scapi.primitives.hash.bc.BcSHA256
BCSHA-384	edu.biu.scapi.primitives.hash.bc.BcSHA384
BCSHA-512	edu.biu.scapi.primitives.hash.bc.BcSHA512

The Crypto++ implementation (explicit keys):

Key	Class
CryptoPPSHA-1	edu.biu.scapi.primitives.hash.cryptopp.CryptoPpSHA1
CryptoPPSHA-224	edu.biu.scapi.primitives.hash.cryptopp.CryptoPpSHA224
CryptoPPSHA-256	edu.biu.scapi.primitives.hash.cryptopp.CryptoPpSHA256
CryptoPPSHA-384	edu.biu.scapi.primitives.hash.cryptopp.CryptoPpSHA384
CryptoPPSHA-512	edu.biu.scapi.primitives.hash.cryptopp.CryptoPpSHA512

The OpenSSL implementation:

Key	Class
OpenSSLSHA-1	edu.biu.scapi.primitives.hash.openSSL.OpenSSLSHA1
OpenSSLSHA-224	edu.biu.scapi.primitives.hash.openSSL.OpenSSLSHA224
OpenSSLSHA-256	edu.biu.scapi.primitives.hash.openSSL.OpenSSLSHA256
OpenSSLSHA-384	edu.biu.scapi.primitives.hash.openSSL.OpenSSLSHA384
OpenSSLSHA-512	edu.biu.scapi.primitives.hash.openSSL.OpenSSLSHA512

Universal Hash

A **universal hash function** is a family of hash functions with the property that a randomly chosen hash function (from the family) yields very few collisions, with good probability. More importantly in a cryptographic context, universal hash functions have important properties, like good randomness extraction and pairwise independence. Many universal families are known (for hashing integers, vectors, strings), and their evaluation is often very efficient.

The notions of universal hashing and cryptographic hash are distinct, and should not be confused (it is unfortunate that they have a similar name). We therefore completely separate the two implementations so that cryptographic hash functions cannot be confused with universal hash functions.

The output length of universal hash function is fixed for any given instantiation. The input is fixed (maybe for a certain instantiation) for some implementations and may be varying for other implementations. Since the input can be either fixed or varying we supply a compute function with input length as an argument for the varying version. The function `getInputLength()` plays a slightly different role for each version.

Contents

The `UniversalHash` interface

public void **`setKey`**(SecretKey *secretKey*)
Sets the secret key for this UH. The key can be changed at any time.

Parameters

- **secretKey** – secret key

Throws InvalidKeyException

public boolean **`isKeySet`**()
An object trying to use an instance of UH needs to check if it has already been initialized.

Returns `true` if the object was initialized by calling the function `setKey`.

public int **`getInputSize`**()
This function has multiple roles depending on the concrete hash function.

If the concrete class can get a varying input lengths then there are 2 possible answers:

1. The maximum size of the input if there is some kind of an upper bound on the input size (for example in the EvaluationHashFunction there is a limit on the input size due to security reasons). Thus, this function returns this bound even though the actual size can be any number between zero and that limit.

2.If there is no limit on the input size, this function returns 0.

Otherwise, if the concrete class can get a fixed length, this function returns a constant size that may be determined either in the init for some implementations or hardcoded for other implementations.

Returns the input size of this hash function

public int **`getOutputSize`**()

Returns the output size of this hash function

public SecretKey **`generateKey`**(AlgorithmParameterSpec *keyParams*)
Generates a secret key to initialize this UH object.

Parameters

- **keyParams** – contains the required parameters for the key generation

Throws InvalidParameterSpecException

Returns the generated secret key

public SecretKey **`generateKey`**(int *keySize*)
Generates a secret key to initialize this UH object.

Parameters

- **keySize** – is the required secret key size in bits

Returns the generated secret key

public void **`compute`**(byte[] *in*, int *inOffset*, int *inLen*, byte[] *out*, int *outOffset*)
Computes the hash function on the in byte array and put the result in the output byte array.

Parameters

- **in** – input byte array
- **inOffset** – the offset within the input byte array
- **inLen** – the number of bytes to take after the offset
- **out** – output byte array

- **outOffset** – the offset within the output byte array

Throws IllegalBlockSizeException if the input length is greater than the upper limit

Example of Usage

```
// create an input array in and an output array out
...

// initiates an EvaluationHashFunction object using the UniversalHashFactory
UniversalHash uh = UniversalHashFactory.getInstance().getObject("ScapiEvaluationHash");

// calls the compute() function in the UniversalHash interface
uh.compute(in, 0, in.length, out, 0);
```

Supported Hash Types

In this section we present possible keys to the `UniversalHashFactory`. Currently, there is only one supported implementation of `UniversalHash`.

Key	Class
ScapiEvaluationHash	edu.biu.scapi.primitives.universalHash.EvaluationHashFunction

Pseudorandom Function (PRF)

In cryptography, a **pseudorandom function family**, abbreviated **PRF**, is a collection of efficiently-computable functions which emulate a random function in the following way: no efficient algorithm can distinguish (with significant advantage) between a function chosen randomly from the PRF family and a random oracle (a function whose outputs are fixed completely at random).

Contents

The `PseudorandomFunction` Interface

The main function of this interface is `computeBlock()`. We supply several versions for compute, with and without length. Since both PRP's and PRF's may have varying input/output length, for such algorithms the length should be supplied. We provide the version without the lengths and not just the versions with length of input and output, although it suffices, to avoid confusion and misuse from a basic user that only knows how to use block ciphers. A user that uses the block cipher TripleDES, may be confused by the "compute with length" functions since TripleDES has a pre-defined length and it cannot be changed.

Block Manipulation

public void **computeBlock**(byte[] *inBytes*, int *inOff*, byte[] *outBytes*, int *outOff*)

Computes the function using the secret key. The user supplies the input byte array and the offset from which to take the data from. The user also supplies the output byte array as well as the offset. The computeBlock function will put the output in the output array starting at the offset. This function is suitable for block ciphers where the input/output length is known in advance.

Parameters

- **inBytes** – input bytes to compute
- **inOff** – input offset in the inBytes array
- **outBytes** – output bytes. The resulted bytes of compute
- **outOff** – output offset in the outBytes array to put the result from

Throws

- **IllegalBlockSizeException** –

public void **computeBlock**(byte[] *inBytes*, int *inOff*, int *inLen*, byte[] *outBytes*, int *outOff*, int *outLen*)

Computes the function using the secret key. This function is provided in the interface especially for the sub-family PrfVaryingIOLength, which may have variable input and output length. If the implemented algorithm is a block cipher then the size of the input as well as the output is known in advance and the use may call the other computeBlock function where length is not require.

Parameters

- **inBytes** – input bytes to compute
- **inOff** – input offset in the inBytes array
- **inLen** – the length of the input array
- **outBytes** – output bytes. The resulted bytes of compute
- **outOff** – output offset in the outBytes array to put the result from
- **outLen** – the length of the output array

Throws

- **IllegalBlockSizeException** –

public void **computeBlock**(byte[] *inBytes*, int *inOffset*, int *inLen*, byte[] *outBytes*, int *outOffset*)

Computes the function using the secret key.

This function is provided in this PseudorandomFunction interface for the sake of interfaces (or classes) for which the input length can be different for each computation. Hmac and Prf/Prp with variable input length are examples of such interfaces.

Parameters

- **inBytes** – input bytes to compute
- **inOffset** – input offset in the inBytes array
- **inLen** – the length of the input array
- **outBytes** – output bytes. The resulted bytes of compute.
- **outOffset** – output offset in the outBytes array to put the result from

Throws

- **IllegalBlockSizeException** –

public int **getBlockSize**()

Returns the input block size in bytes

Setting the Secret Key

public SecretKey **generateKey**(AlgorithmParameterSpec *keyParams*)
Generates a secret key to initialize this prf object.

Parameters

- **keyParams** – algorithmParameterSpec contains the required parameters for the key generation

Throws

- **InvalidParameterSpecException** –

Returns the generated secret key

public SecretKey **generateKey**(int *keySize*)
Generates a secret key to initialize this prf object.

Parameters

- **keySize** – is the required secret key size in bits

Returns the generated secret key

public boolean **isKeySet**()
An object trying to use an instance of prf needs to check if it has already been initialized.

Returns true if the object was initialized by calling the function setKey.

public void **setKey**(SecretKey *secretKey*)
Sets the secret key for this prf. The key can be changed at any time.

Parameters

- **secretKey** – secret key

Throws

- **InvalidKeyException** –

Basic Usage

```
//Create secretKey and in, in2, out byte arrays
...

// initiate a PRF of type TripleDES using the PrfFactory
PseudorandomFunction prf = PrfFactory.getInstance().getObject("TripleDES")

//set the key
prf.setKey(secretKey);

//compute the function with input in and output out.
prf.computeBlock(in, 0, out, 0);
```

Pseudorandom Function with Varying Input-Output Lengths

A pseudorandom function with varying input/output lengths does not have pre-defined input and output lengths. The input and output length may be different for each compute function call. The length of the input as well as the output is determined upon user request. The class `IteratedPrfVarying` implements this functionality using an inner PRF that must implement the `PrfVaryingInputLength` interface. An example for such PRF is `Hmac`.

How to use the Varying Input-Output Length PRF

```
//Create secret key and in, out byte arrays
...

//call the PrfFactory.
PseudorandomFunction prf = PrfFactory.getInstance().getObject("IteratedPrfVarying(Hmac(SHA-1))");

//set the key
prf.setKey(secretKey);

//compute the function with input in of size 10 and output out of size 20.
prf.computeBlock(in, 0, 10, out, 0, 20);
```

Pseudorandom Permutation (PRP)

Pseudorandom permutations are bijective pseudorandom functions that are *efficiently invertible*. As such, they are of the pseudorandom function type and their input length always equals their output length. In addition (and unlike general pseudorandom functions), they are efficiently invertible.

The `PseudorandomPermutation` Interface

The `PseudorandomPermutation` interface extends the `PseudorandomFunction` interface, and adds the following functionality.

public void **`invertBlock`** (byte[] *inBytes*, int *inOff*, byte[] *outBytes*, int *outOff*)

Inverts the permutation using the given key.

This function is a part of the PseudorandomPermutation interface since any PseudorandomPermutation must be efficiently invertible (given the key). For block ciphers, for example, the length is known in advance and so there is no need to specify the length.

Parameters

- **inBytes** – input bytes to invert.
- **inOff** – input offset in the inBytes array
- **outBytes** – output bytes. The resulted bytes of invert
- **outOff** – output offset in the outBytes array to put the result from

Throws

- **IllegalBlockSizeException** –

public void **`invertBlock`** (byte[] *inBytes*, int *inOff*, byte[] *outBytes*, int *outOff*, int *len*)

Inverts the permutation using the given key.

Since PseudorandomPermutation can also have varying input and output length (although the input and the output should be the same length), the common parameter `len` of the input and the output is needed.

Parameters

- **inBytes** – input bytes to invert.
- **inOff** – input offset in the inBytes array
- **outBytes** – output bytes. The resulted bytes of invert
- **outOff** – output offset in the outBytes array to put the result from
- **len** – the length of the input and the output

Throws

- **IllegalBlockSizeException** –

Basic Usage

```
//Create secretKey and in, out, inv byte arrays
...

//call the PrfFactory and cast to prp
PseudorandomPermutation prp = (PseudorandomPermutation) PrfFactory.getInstance().getObject("OpenSSL",

//set the key
prp.setKey(secretKey);

//run the permutation on a block-size prefix of in[]
prp.computeBlock(in, 0, out, 0);

//invert the permutation
prp.invertBlock(out, 0, inv, 0);
```

Pseudorandom Permutation with Varying Input-Output Lengths

A pseudorandom permutation with varying input/output lengths does not have pre-defined input/output lengths. The input and output length (that must be equal) may be different for each function call. The length of the input/output is determined upon user request.

We implement the Luby-Rackoff algorithm as an example of PRP with varying I/O lengths. The class that implements the algorithm is `LubyRackoffPrpFromPrfVarying`.

How to use the Varying Input-Output Length PRP

```
//Create secretKey and in, out byte arrays
...

//call the PrfFactory and cast to prp
PseudorandomPermutation prp = (PseudorandomPermutation) PrfFactory.getInstance().getObject("LubyRacko

//set the key
prp.setKey(secretKey);

//invert the permutation with input in and output out of common size 20.
prp.invertBlock(in, 0, out, 0, 20);
```

Pseudorandom Generator (PRG)

A **pseudorandom generator (PRG)** is a deterministic algorithm that takes a "short" uniformly distributed string, known as *the seed*, and outputs a longer string that cannot be efficiently distinguished from a uniformly distributed string of that length.

The `PseudorandomGenerator` Interface

public void **`getPRGBytes`** (byte[] *outBytes*, int *outOffset*, int *outlen*)
Streams the prg bytes.

Parameters

- **outBytes** – output bytes. The result of streaming the bytes.
- **outOffset** – output offset
- **outlen** – the required output length

Basic Usage

```
//Create secret key and out byte array
...

//Create prg using the PrgFactory
PseudorandomGenerator prg = PrgFactory.getInstance().getObject("RC4");
SecretKey secretKey = prg.generateKey(256); //256 is the key size in bits.

//set the key
Prg.setKey(secretKey);

//get PRG bytes. The caller is responsible for allocating the out array.
//The result will be put in the out array.
prg.getPRGBytes(out.length, out);
```

Trapdoor Permutation

A trapdoor permutation is a bijection (1-1 and onto function) that is easy to compute for everyone, yet is hard to invert unless given special additional information, called the "trapdoor". The public key is essentially the function description and the private key is the trapdoor.

Contents

The `TPElement` Interface

The `TPElement` interface represents a trapdoor permutation element.

public BigInteger **`getElement`**`()`
Returns the trapdoor element value as BigInteger.

Returns the value of the element

public TPElementSendableData **`generateSendableData`**`()`
This function extracts the actual value of the TPElement and wraps it in a TPElementSendableData that as it name indicates can be send using the serialization mechanism.

Returns A Serializable representation of the TPElement

The `TrapdoorPermutation` Interface

This interface is the general interface of trapdoor permutation.

Core Functionality

public TPElement **`compute`**(TPElement *tpEl*)
Computes the operation of this trapdoor permutation on the given TPElement.

Parameters

- **tpEl** – the input for the computation

Returns the result TPElement from the computation

Throws IllegalArgumentException if the given element is invalid for this permutation

public TPElement **`invert`**(TPElement *tpEl*)
Inverts the operation of this trapdoor permutation on the given TPElement.

Parameters

- **tpEl** – the input to invert

Returns the result TPElement from the invert operation

Throws KeyException if there is no private key

Throws IllegalArgumentException if the given element is invalid for this permutation

public byte **`hardCorePredicate`**(TPElement *tpEl*)
Computes the hard core predicate of the given tpElement.

A hard-core predicate of a one-way function f is a predicate b (i.e., a function whose output is a single bit) which is easy to compute given x but is hard to compute given $f(x)$. In formal terms, there is no probabilistic polynomial time algorithm that computes $b(x)$ from $f(x)$ with probability significantly greater than one half over random choice of x.

Parameters

- **tpEl** – the input to the hard core predicate

Returns (byte) the hard core predicate.

public byte[] **`hardCoreFunction`**(TPElement *tpEl*)
Computes the hard core function of the given tpElement.

A hard-core function of a one-way function f is a function g which is easy to compute given x but is hard to compute given $f(x)$. In formal terms, there is no probabilistic polynomial time algorithm that computes $g(x)$ from $f(x)$ with probability significantly greater than one half over random choice of x.

Parameters

- **tpEl** – the input to the hard core function

Returns byte[] the result of the hard core function

Generating TPElements

public TPElement **generateRandomTPElement**()
creates a random TPElement that is valid for this trapdoor permutation

Returns the created random element

public TPElement **generateTPElement**(BigInteger *x*)
Creates a TPElement from a specific value x. It checks that the x value is valid for this trapdoor permutation.

Returns If the x value is valid for this permutation return the created random element

Throws IllegalArgumentException if the given value x is invalid for this permutation

public TPElement **generateUncheckedTPElement**(BigInteger *x*)
Creates a TPElement from a specific value x. This function does not guarantee that the the returned `TPElement` object is valid. It is the caller's responsibility to pass a legal x value.

Returns Set the x value and return the created random element

public TPElement **reconstructTPElement**(TPElementSendableData *data*)
Creates a TPElement from data that was probably obtained via the serialization mechanism.

Parameters

- **data** – serialized data necessary to reconstruct a given TPElement

Returns the reconstructed TPElement

Checking Element Validity

public TPElValidity **isElement**(TPElement *tpEl*)
Checks if the given element is valid for this trapdoor permutation

Parameters

- **tpEl** – the element to check

Returns (TPElValidity) enum number that indicate the validation of the element

Throws IllegalArgumentException if the given element is invalid for this permutation

public enum **TPElValidity**
Enum that represent the possible validity values of trapdoor element. There are three possible validity values:

Parameters

- **VALID** – it is an element
- **NOT_VALID** – it is not an element
- **DONT_KNOW** – there is not enough information to check if it is an element or not

Encryption Keys Functionality

public void **setKey** (PublicKey *publicKey*, PrivateKey *privateKey*)
Sets this trapdoor permutation with public key and private key.

Parameters

- **publicKey** – the public key
- **privateKey** – the private key that without it the permutation cannot be inverted efficiently

public void **setKey** (PublicKey *publicKey*)
Sets this trapdoor permutation with a public key. After this initialization, this object can do `compute()` but not `invert()`. This initialization is for user that wants to encrypt messages using the public key but cannot decrypt messages.

Parameters

- **publicKey** – the public key

Throws InvalidKeyException if the key is not a valid key of this permutation

public boolean **isKeySet** ()

Checks if this trapdoor permutation object has been previously initialized. To initialize the object the `setKey()` function has to be called with corresponding parameters after construction.

return `true` if the object was initialized, `false` otherwise.

public PublicKey **getPubKey** ()

Returns returns the public key

BasicUsage

We demonstrate a basic usage scenario with a sender party that wish to hide a secret using the trapdoor permutation, and a receiver who is not able to invert the permutation on the secret.

Here is the code of the sender:

```
//Create public key, private key and secret
...

//instantiate the trapdoor permutation:
TrapdoorPermutation trapdoorPermutation = TrapdoorPermutationFactory.getInstance().getObject("RSA", "
//set the keys for this trapdoor permutation
trapdoorPermutation.setKey(publicKey, privateKey);

// represent the secret (originally was of BigInteger type) using TPElement
TPElement secretElement = trapdoorPermutation.generateTPElement(secret);
//hide the secret using the trapdoor permutation
TPElement maskedSecret = trapdoorPermutation.compute(secretElement);

// this line will succeed, because the private key is known to the sender
TPElement invertedElement = trapdoorPermutation.invert(maskedSecret);

// send the public key and the secret to the other side
channel.send(publicKey.getEncoded());
channel.send(maskedSecret.generateSendableData());
```

Here is the code of the receiver:

```
Serializable pkey = channel.receive();
TPElementSendableData secretMsg = (TPElementSendableData) channel.receive();

// reconstruct publicKey from pkey
...

//instantiate the trapdoor permutation:
TrapdoorPermutation trapdoorPermutation = TrapdoorPermutationFactory.getInstance().getObject("RSA", "
//set the keys for this trapdoor permutation
trapdoorPermutation.setKey(publicKey);

// reconstruct a TPElement from a TPElementSendableData
TPElement maskedSecret = trapdoorPermutation.reconstructTPElement(secretMsg);

// this line will fail, and throw KeyException, because the private key is not known to the receiver
TPElement secretElement = trapdoorPermutation.invert(maskedSecret);
```

Supported Trapdoor Permutations

In this section we present possible keys to the `TrapdoorPermutationFactory`.

Scapi's own implementation of RSA trapdoor permutation:

Key	Class
ScapiRSA	edu.biu.scapi.primitives.trapdoorPermutation.ScRSAPermutation

Crypto++ implementation of RSA trapdoor permutation and Rabin trapdoor permutation:

Key	Class
CryptoPPRSA	edu.biu.scapi.primitives.trapdoorPermutation.cryptopp.CryptoPpRSAPermutation
CryptoPPRabin	edu.biu.scapi.primitives.trapdoorPermutation.cryptopp.CryptoPpRabinPermutation

OpenSSL implementation of RSA trapdoor permutation:

Key	Class
OpenSSLRSA	edu.biu.scapi.primitives.trapdoorPermutation.openSSL.OpenSSLRSAPermutation

Discrete Log Group

The **discrete logarithm problem** is as follows: given a generator g of a finite group G and a random element $h \in G$, find the (unique) integer x such that $g^x = h$. In cryptography, we are interested in groups for which the discrete logarithm problem (Dlog for short) is assumed to be hard (or other discrete-log type assumptions like **CDH** and **DDH**). The two most common classes are a prime subgroup of the group Z_p^* for a large p, and some Elliptic curve groups.

We provide the implementation of the most important Dlog groups in cryptography (see diagram below):

- Z_p^*
- Elliptic curve over the field $GF[2^m]$
- Elliptic curve over the field Z_p

Although Elliptic curves groups look very different, the discrete log problem over them can be described as follows. Given an elliptic curve E over a finite field F, a base point on that curve P (i.e., a generator of the group defined from the curve), and a random point Q on the curve, the problem is to find the integer n such that $nP = Q$.

We have currently incorporated the elliptic curves recommended by NIST.

Contents

Class Hierarchy:

The root of the family is a general Dlog Group that presents functionality that all Dlog Groups should implement.

At the second level we encounter three interfaces:

1. PrimeOrderSubGroup: The order q of the group must be a prime.
2. DlogZp: Dlog Group over the Z_p^* field.
3. DlogEllipticCurve: Any elliptic curve.

At the third level we have:

1. DlogZpSafePrime: The order q is not only a prime but also is such that prime $p = 2 * q + 1$.
2. DlogEcFp: Any elliptic curve over F_p.
3. DlogEcF2m: Any elliptic curve over $F_2[m]$.

All these are general interfaces. Specifically, we implement Dlog Groups that are of prime order; therefore all the concrete classes presented here implement this interface. Other implementations may choose to add Dlog Groups that are not of prime order, and they are at liberty of doing so. They just need not to declare that they implement the PrimeOrderSubGroup interface.

We also see in the diagram two other interfaces that are **used** by DlogGroup:

1. GroupParams.
2. GroupElement.

The `DlogGroup` Interface

Group Parameters

public GroupElement **`getGenerator`**`()`

The generator g of the group is an element of the group such that, when written multiplicatively, every element of the group is a power of g.

Returns the generator of this Dlog group

public GroupElement **createRandomGenerator**()
Creates a random generator of this Dlog group

Returns the random generator

public BigInteger **getOrder**()

Returns the order of this Dlog group

public GroupParams **getGroupParams**()
GroupParams is a structure that holds the actual data that makes this group a specific Dlog group. For example, for a Dlog group over Zp* what defines the group is p.

Returns the GroupParams of that Dlog group

public String **getGroupType**()
Each concrete class implementing this interface returns a string with a meaningful name for this type of Dlog group. For example: "elliptic curve over F2m" or "Zp*"

Returns the name of the group type

public GroupElement **getIdentity**()

Returns the identity of this Dlog group

Exponentiation

public GroupElement **exponentiate**(GroupElement *base*, BigInteger *exponent*)
Raises the base GroupElement to the exponent. The result is another GroupElement.

Parameters

- **base** –
- **exponent** –

Throws

- **IllegalArgumentException** –

Returns the result of the exponentiation

public GroupElement **exponentiateWithPreComputedValues**(GroupElement *base*, BigInteger *exponent*)
Computes the product of several exponentiations of the same base and distinct exponents. An optimization is used to compute it more quickly by keeping in memory the result of h1, h2, h4,h8,... and using it in the calculation.

Note that if we want a one-time exponentiation of h it is preferable to use the basic exponentiation function since there is no point to keep anything in memory if we have no intention to use it.

Parameters

- **base** –
- **exponent** –

Returns the exponentiation result

public void **endExponentiateWithPreComputedValues**(GroupElement *base*)
This function cleans up any resources used by exponentiateWithPreComputedValues for the requested base. It is recommended to call it whenever an application does not need to continue calculating exponentiations for this specific base.

Parameters

- **base** –

public GroupElement **simultaneousMultipleExponentiations**(GroupElement[] *groupElements*, BigInteger[] *exponentiations*)

Computes the product of several exponentiations with distinct bases and distinct exponents. Instead of computing each part separately, an optimization is used to compute it simultaneously.

Parameters

- **groupElements** –
- **exponentiations** –

Returns the exponentiation result

Multiplication and Inverse

public GroupElement **getInverse**(GroupElement *groupElement*)

Calculates the inverse of the given GroupElement.

Parameters

- **groupElement** – to invert

Throws

- **IllegalArgumentException** –

Returns the inverse element of the given GroupElement

public GroupElement **multiplyGroupElements**(GroupElement *groupElement1*, GroupElement *groupElement2*)

Multiplies two GroupElements

Parameters

- **groupElement1** –
- **groupElement2** –

Throws

- **IllegalArgumentException** –

Returns the multiplication result

Group Element Generation

public GroupElement **createRandomElement**()

Creates a random member of this Dlog group

Returns the random element

public GroupElement **generateElement**(boolean *bCheckMembership*, BigInteger... *values*)

This function allows the generation of a group element by a protocol that holds a Dlog Group but does not know if it is a Zp Dlog Group or an Elliptic Curve Dlog Group. It receives the possible values of a group element and whether to check membership of the group element to the group or not.

It may be not necessary to check membership if the source of values is a trusted source (it can be the group itself after some calculation). On the other hand, to work with a generated group element that is not really an element in the group is wrong. It is up to the caller of the function to decide if to check membership or not. If bCheckMembership is false always generate the element. Else, generate it only if the values are correct.

Parameters

- **bCheckMembership** –
- **values** –

Throws

- **IllegalArgumentException** –

Returns the generated GroupElement

Validation

public boolean **isGenerator**()
Checks if the element set as the generator is indeed the generator of this group.

Returns `true` if the generator is valid, `false` otherwise.

public boolean **isMember**(GroupElement *element*)
Checks if the given element is a member of this Dlog group

Parameters

- **element** – possible group element for which to check that it is a member of this group

Throws

- **IllegalArgumentException** –

Returns `true` if the given element is a member of this group, `false` otherwise.

public boolean **validateGroup**()
Checks parameters of this group to see if they conform to the type this group is supposed to be.

Returns `true` if valid, `false` otherwise.

Group Classification

public boolean **isOrderGreaterThan**(int *numBits*)
Checks if the order of this group is greater than 2^numBits

Parameters

- **numBits** –

Returns `true` if the order is greater than 2^numBits, `false` otherwise.

public boolean **isPrimeOrder**()
Checks if the order is a prime number

Returns true if the order is a prime number, false otherwise.

Group Element Serialization

public GroupElement **reconstructElement**(boolean *bCheckMembership*, GroupElementSendableData *data*)
Reconstructs a GroupElement given the GroupElementSendableData data, which might have been received through a Channel open between the party holding this DlogGroup and some other party.

Parameters

- **bCheckMembership** – whether to check that the data provided can actually reconstruct an element of this DlogGroup. Since this action is expensive it should be used only if necessary.
- **data** – the GroupElementSendableData from which we wish to "reconstruct" an element of this DlogGroup

Returns the reconstructed GroupElement

Byte Array Encoding

public GroupElement **`encodeByteArrayToGroupElement`**(byte[] *binaryString*)

This function takes any string of length up to k bytes and encodes it to a Group Element. k can be obtained by calling getMaxLengthOfByteArrayForEncoding() and it is calculated upon construction of this group; it depends on the length in bits of p.

The encoding-decoding functionality is not a bijection, that is, it is a 1-1 function but **is not onto**. Therefore, any string of length in bytes up to k can be encoded to a group element but not every group element can be decoded to a binary string in the group of binary strings of length up to 2^k.

Thus, the right way to use this functionality is first to encode a byte array and then to decode it, and not the opposite.

Parameters

- **binaryString** – the byte array to encode

Returns the encoded group Element **or null** if the string could not be encoded

public byte[] **`decodeGroupElementToByteArray`**(GroupElement *groupElement*)

This function decodes a group element to a byte array. This function is guaranteed to work properly **ONLY** if the group element was obtained as a result of encoding a binary string of length in bytes up to k.

This is because the encoding-decoding functionality is not a bijection, that is, it is a 1-1 function but **is not onto**. Therefore, any string of length in bytes up to k can be encoded to a group element but not any group element can be decoded to a binary sting in the group of binary strings of length up to 2^k.

Parameters

- **groupElement** – the element to decode

Returns the decoded byte array

public int **`getMaxLengthOfByteArrayForEncoding`**()

This function returns the value *k* which is the maximum length of a string to be encoded to a Group Element of this group. Any string of length *k* has a numeric value that is less than (p-1)/2. *k* is the maximum length a binary string is allowed to be in order to encode the said binary string to a group element and vice-versa. If a string exceeds the *k* length it cannot be encoded.

Returns k the maximum length of a string to be encoded to a Group Element of this group. k can be zero if there is no maximum.

public byte[] **`mapAnyGroupElementToByteArray`**(GroupElement *groupElement*)

This function maps a group element of this dlog group to a byte array. This function does not have an inverse function, that is, it is not possible to re-construct the original group element from the resulting byte array.

Returns a byte array representation of the given group element

The `GroupElement` Interface

public GroupElementSendableData **`generateSendableData`**`()`
This function is used when a group element needs to be sent via a `edu.biu.scapi.comm.Channel` or any other means of sending data (including serialization). It retrieves all the data needed to reconstruct this Group Element at a later time and/or in a different VM. It puts all the data in an instance of the relevant class that implements the GroupElementSendableData interface.

Returns the GroupElementSendableData object

public boolean **`isIdentity`**`()`
checks if this element is the identity of the group.

Returns `true` if this element is the identity of the group, `false` otherwise.

The `GroupParams` Interface

public BigInteger **`getQ`**`()`

Returns the group order q

Basic Usage

```
// initiate a discrete log group (in this case the OpenSSL implementation of the elliptic curve group
DlogGroup dlog = new OpenSSLDlogECF2m("K-233");
SecureRandom random = new SecureRandom();

// get the group generator and order
GroupElement g = dlog.getGenerator();
BigInteger q = dlog.getOrder();
BigInteger qMinusOne = q.subtract(BigInteger.ONE);

// create a random exponent r
BigInteger r = BigIntegers.createRandomInRange(BigInteger.ZERO, qMinusOne, random);
// exponentiate g in r to receive a new group element
GroupElement g1 = dlog.exponentiate(g, r);
// create a random group element

GroupElement h = dlog.createRandomElement();
// multiply elements
GroupElement gMult = dlog.multiplyGroupElements(g1, h);
```

key Derivation Function

A key derivation function (or KDF) is used to derive (close to) uniformly distributed string/s from a secret value with high entropy (but no other guarantee regarding its distribution).

Contents

The `Key Derivation Function` Interface:

public SecretKey **`deriveKey`** (byte[] *entropySource*, int *inOff*, int *inLen*, int *outLen*)
Generates a new secret key from the given seed.

Parameters

- **entropySource** – the secret key that is the seed for the key generation
- **inOff** – the offset within the entropySource to take the bytes from
- **inLen** – the length of the seed
- **outLen** – the required output key length

Returns SecretKey the derivated key.

There is another variation of this function, that also takes into account an initial vector (iv):

public SecretKey **`deriveKey`** (byte[] *entropySource*, int *inOff*, int *inLen*, int *outLen*, byte[] *iv*)
Generates a new secret key from the given seed and iv.

Parameters

- **entropySource** – the secret key that is the seed for the key generation
- **inOff** – the offset within the entropySource to take the bytes from
- **inLen** – the length of the seed
- **outLen** – the required output key length
- **iv** – info for the key generation

Returns SecretKey the derivated key.

Basic Usage

```
KeyDerivationFunction kdf = new HKDF(new BcHMAC());
byte[] source = "...";
int targetLen = 128;
byte[] kdfed = kdf.deriveKey(source, 0, source.length, targetLen).getEncoded();
```

Layer 2: Non Interactive Protocols

The second layer of Scapi includes different symmetric and asymmetric encryption schemes, message authentication codes and digital signatures. It heavily uses the primitives of the first layer to perform internal operations. For example, the ElGamal encryption scheme uses DlogGroup; CBC-MAC uses any of the PRPs defined in the first level.

Message Authentication Codes

In cryptography, a Message Authentication Code (MAC) is a short piece of information used to authenticate a message and to provide integrity and authenticity assurances on the message. Integrity assurances detect accidental and intentional message changes, while authenticity assurances affirm the message's origin. Scapi provides two implementations of message authentication codes: CBC-MAC and HMAC.

Contents

The Mac Interface

This is the general interface for Mac. Every class in this family must implement this interface.

public interface **Mac**

Basic Mac and Verify Functionality

public byte[] **mac** (byte[] *msg*, int *offset*, int *msgLen*)
Computes the mac operation on the given msg and return the calculated tag.

Parameters

- **msg** – the message to operate the mac on.
- **offset** – the offset within the message array to take the bytes from.
- **msgLen** – the length of the message in bytes.

Returns byte[] the return tag from the mac operation.

public boolean **verify** (byte[] *msg*, int *offset*, int *msgLength*, byte[] *tag*)
Verifies that the given tag is valid for the given message.

Parameters

- **msg** – the message to compute the mac on to verify the tag.
- **offset** – the offset within the message array to take the bytes from.
- **msgLength** – the length of the message in bytes.
- **tag** – the tag to verify.

Returns true if the tag is the result of computing mac on the message. false, otherwise.

Calulcating the Mac when not all the message is known up front

public void **update** (byte[] *msg*, int *offset*, int *msgLen*)
Adds the byte array to the existing message to mac.

Parameters

- **msg** – the message to add.
- **offset** – the offset within the message array to take the bytes from.
- **msgLen** – the length of the message in bytes.

public byte[] **doFinal**(byte[] *msg*, int *offset*, int *msgLength*)
Completes the mac computation and puts the result tag in the tag array.

Parameters

- **msg** – the end of the message to mac.
- **offset** – the offset within the message array to take the bytes from.
- **msgLength** – the length of the message in bytes.

Returns the result tag from the mac operation.

Key Handling

public SecretKey **generateKey**(int *keySize*)
Generates a secret key to initialize this mac object.

Parameters

- **keySize** – is the required secret key size in bits.

Returns the generated secret key.

public SecretKey **generateKey**(AlgorithmParameterSpec *keyParams*)
Generates a secret key to initialize this mac object.

Parameters

- **keyParams** – algorithmParameterSpec contains parameters for the key generation of this mac algorithm.

Throws

- **InvalidParameterSpecException** – if the given keyParams does not match this mac algoithm.

Returns the generated secret key.

public boolean **isKeySet**()
An object trying to use an instance of mac needs to check if it has already been initialized.

Returns true if the object was initialized by calling the function setKey.

public void **setKey**(SecretKey *secretKey*)
Sets the secret key for this mac. The key can be changed at any time.

Parameters

- **secretKey** – secret key

Throws

- **InvalidKeyException** – if the given key does not match this MAC algorithm.

Mac Properties

public int **getMacSize**()
Returns the input block size in bytes.

Returns the input block size.

CBC-MAC

A **Cipher Block Chaining Message Authentication Code**, abbreviated **CBC-MAC**, is a technique for constructing a message authentication code from a block cipher. The message is processed with some block cipher algorithm in CBC mode to create a chain of blocks such that each block depends on the previous blocks. This interdependence ensures that a change to any of the plaintext bits will cause the final encrypted block to change in a way that cannot be predicted or counteracted without knowing the key to the block cipher. The initialization vector (IV) usually present in CBC encryption is set to zero when a CBC MAC is computed (i.e., there is no IV). In addition, in order for CBC-MAC to be secure for variable-length messages, the length of the message has to be pre-pended to the message in the first block before beginning CBC-MAC. When computed in this way, CBC-MAC is a PRF and thus a secure MAC.

Note: We remark that if the length of the message is not known in advance then a different MAC algorithm should be used (for example: HMAC).

The CbcMac Interface

The CbcMac interface is th general interface for CBC-Mac. Every class that implement the CBC-Mac algorithm should implement this interface.

public interface **CbcMac** extends UniqueTagMac, PrfVaryingInputLength, UnlimitedTimes

public void **startMac**(int *msgLength*)
Pre-pends the length if the message to the message. As a result, the mac will be calculated on [msgLength||msg].

Parameters

- **msgLength** – the length of the message in bytes.

Basic Usage

```
// assume we have a message msg
byte[] msg;

// initialize a secure random object
SecureRandom random = new SecureRandom();

// initialize a prp to be used by the CbcMac algorithm
PseudorandomPermutation prp = new OpenSSLAES(random);
SecretKey secretKey = prp.generateKey(128);
prp.setKey(secretKey);

// initialize the CbcMac algorithm
CbcMac mac = new ScCbcMacPrepending(prp, random);

// calculate the tag on a complete message
byte[] tag = mac.mac(msg, 0, msg.length);
```

```
// compute the mac in stages (in case not all the message is known up front)
mac.startMac(100);
mac.update(msg, 0, 20);
mac.update(msg, 20, 20);
mac.update(msg, 40, 20);
mac.update(msg, 60, 20);
mac.doFinal(msg, 80, 20);
```

HMAC

We presented the same HMAC algorithm in the first layer of Scapi. However, there it was only presented as a PRF. In order to make HMAC become also a MAC and not just a PRF, all we have to do is to implement the Mac interface. This means that now our HMAC needs to know how to mac and verify. HMAC is a mac that does not require knowing the length of the message in advance.

The Hmac Interface

Hmac is a Marker interface. Every class that implements it is signed as Hmac. Hmac has varying input length and thus implements the interface PrfVaryingInputLength. Currenty the `BcHMAC` class implements the `Hmac` interface.

public interface **`Hmac`** extends PrfVaryingInputLength, UniqueTagMac, UnlimitedTimes

Basic Usage

Sender usage:

```
//Create an hmac object.
Mac hmac = new BcHMAC("SHA-1");

//Generate a SecretKey
Hmac.generateKey(128);

//Set the secretKey.
hmac.setKey(secretKey);

//Get the message to mac and calculate the mac tag.
byte[] tag = hmac.mac(msg, offset, length);

//Send the msg and tag to the receiver.
...
```

Receiver usage:

```
//Get secretKey, msg and tag byte arrays.
...
//Create the same hmac object as the sender's hmac object and set the key.
...
// receive the message and the tag
...
// Verify the tag with the given msg.
If (hmac.verify(tag, msg, offset, length)) { //Tag is valid.
    //Continue working...
} else throw new IllegalStateException() //Tag is not valid.
```

Symmetric Encryption

Scapi implements three main categories of symmetric encryption:

1. An encryption based on modes of operation using a pseudo-random permutation and a randomized IV. The randomized IV is crucial for security. **CBCEnc** and **CTREnc** belong to this category.
2. An authenticated encryption where the message gets first encrypted and then mac-ed. **EncryptThenMac** belongs to this category.
3. Homomorphic encryption. Even though we do not currently implement any concrete homomorphic encryption, we provide the interfaces for future possible implementations.

The symmetric encryption family of classes implements three main functionalities that correspond to the cryptographer's language in which an encryption scheme is composed of three algorithms:

1. Generation of the key.
2. Encryption of the plaintext.
3. Decryption of the ciphertext.

Note: We note that for authenticated encryption, two secret keys will be used, one for the encryption and one for the authentication.

Contents

The SymmetricEnc Interface

public interface **`SymmetricEnc`** extends Eav, Indistinguishable

This is the main interface for the Symmetric Encryption family. Any symmetric encryption scheme belongs by default at least to the Eavsdropper Security Level and to the Indistinguishable Security Level.

Encryption and Decryption

public SymmetricCiphertext **`encrypt`**(Plaintext *plaintext*)

Encrypts a plaintext. It lets the system choose the random IV.

Parameters

- **plaintext** –

Throws

- **IllegalArgumentException** – if the given plaintext does not match this encryption scheme.

- **IllegalStateException** – if no secret key was set.

Returns an IVCiphertext, which contains the IV used and the encrypted data.

public SymmetricCiphertext **encrypt** (Plaintext *plaintext*, byte[] *iv*)
This function encrypts a plaintext. It lets the user choose the random IV.

Parameters

- **plaintext** –
- **iv** – random bytes to use in the encryption pf the message.

Throws

- **IllegalArgumentException** – if the given plaintext does not match this encryption scheme.
- **IllegalBlockSizeException** – if the given IV length is not as the block size.
- **IllegalStateException** – if no secret key was set.

Returns an IVCiphertext, which contains the IV used and the encrypted data.

public Plaintext **decrypt** (SymmetricCiphertext *ciphertext*)
This function performs the decryption of a ciphertext returning the corresponding decrypted plaintext.

Parameters

- **ciphertext** – The Ciphertext to decrypt.

Throws

- **IllegalArgumentException** – if the given ciphertext does not match this encryption scheme.
- **IllegalStateException** – if no secret key was set.

Returns the decrypted plaintext.

Key Generation

public SecretKey **generateKey** (AlgorithmParameterSpec *keyParams*)
Generates a secret key to initialize this symmetric encryption.

Parameters

- **keyParams** – algorithmParameterSpec contains parameters for the key generation of this symmetric encryption.

Throws

- **InvalidParameterSpecException** – if the given keyParams does not match this symmetric encryption.

Returns the generated secret key.

public SecretKey **generateKey** (int *keySize*)
Generates a secret key to initialize this symmetric encryption.

Parameters

- **keySize** – is the required secret key size in bits.

Returns the generated secret key.

Key Handling

public boolean **isKeySet**()
An object trying to use an instance of symmetric encryption needs to check if it has already been initialized.

Returns true if the object was initialized by calling the function setKey.

public void **setKey**(SecretKey *secretKey*)
Sets the secret key for this symmetric encryption. The key can be changed at any time.

Parameters

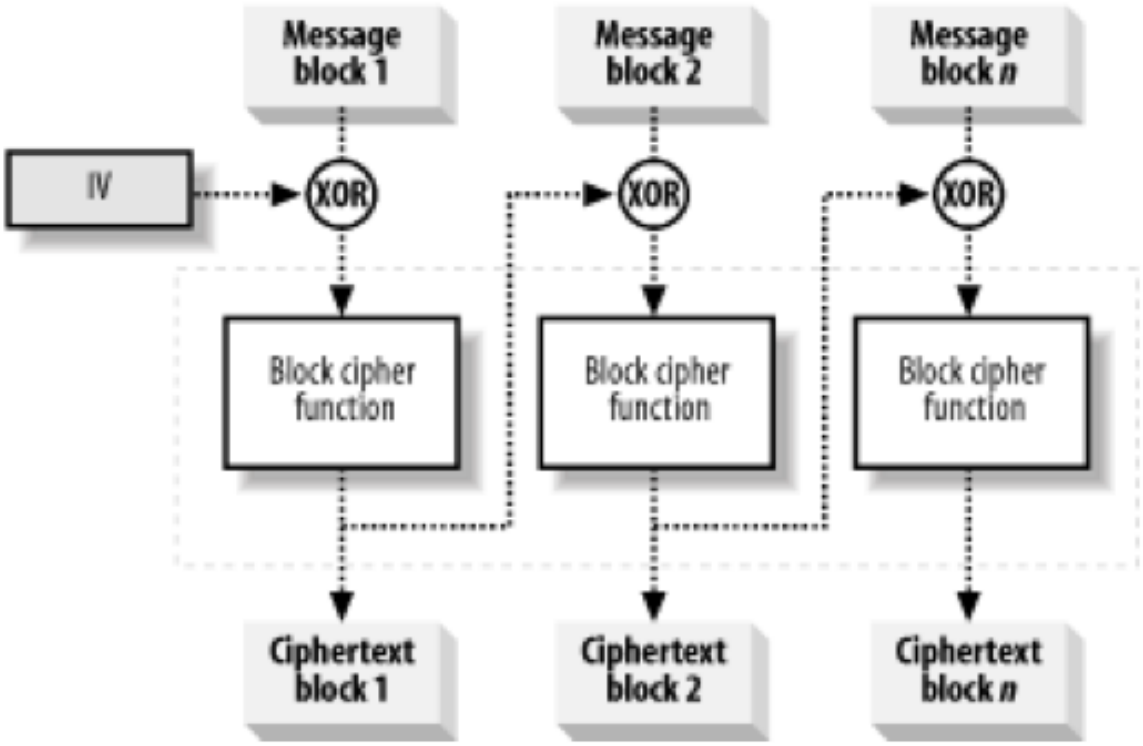
- **secretKey** – secret key.

Throws

- **InvalidKeyException** – if the given key does not match this encryption scheme.

The CBCEnc Interface

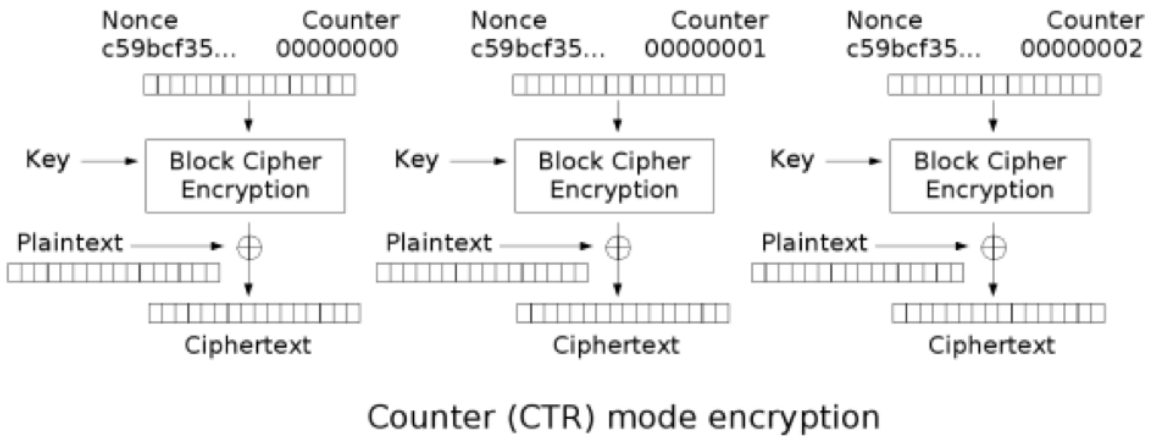
These is a marker interface, for the CBC method:



public interface **CBCEnc** extends SymmetricEnc, Cpa

The CTREnc Interface

These is a marker interface, for the CTR method:



public interface **CTREnc** extends SymmetricEnc, Cpa

Basic Usage

Sender usage:

```
//Create an encryption object. The created object is a CTR-AES encryption scheme object.
SymmetricEnc encryptor = new ScCTREncRandomIV("AES");

//Generate a SecretKey using the created object and set it.
SecretKey key = encryptor.generateKey(128);
encryptor.setKey(key);

//Get a plaintext to encrypt, and encrypt the plaintext.
...
SymmetricCiphertext cipher = Encryptor.encrypt(plaintext);

//Send the cipher to the decryptor.
...
```

Receiver usage:

```
//Create the same SymmetricEnc object as the sender's encryption object, and set the key.
//Get the ciphertext and decrypt it to get the plaintext.
Plaintext plaintext = decryptor.decrypt(cipher);
```

The AuthenticatedEnc Interface

public interface **AuthenticatedEnc** extends SymmetricEnc, Cca2

public class **ScEncryptThenMac** implements AuthenticatedEnc

This class implements a type of authenticated encryption: encrypt then mac.

The encryption algorithm first encrypts the message and then calculates a mac on the encrypted message.

The decrypt algorithm receives an encrypted message and a tag. It first verifies the encrypted message with the tag. If verifies, then it proceeds to decrypt using the underlying decrypt algorithm, if not returns a null response.

This encryption scheme achieves Cca2 and NonMalleable security level.

Basic Usage

```
//Create the PRP that is used by the encryption object.
AES aes = new BcAES();

//Create encryption object.
SymmetricEnc enc = new ScCTREncRandomIV(aes);

//Create the PRP that is used by the Mac object.
TripleDES tripleDes = new BcTripleDES();

//Create Mac object.
Mac cbcMac = new ScCbcMacPrepending(tripleDes);

//Create the encrypt-then-mac object using encryption and authentication objects.
ScEncryptThenMac encThenMac = new ScEncryptThenMac(enc, cbcMac);

// prepare the plaintext
Plaintext plaintext;
...

// encrypt
SymmetricCiphertext cipher = encThenMac.encrypt(plaintext);

// decrypt
Plaintext decrypted = encThenMac.decrypt(cypher);
```

Asymmetric Encryption

Asymmetric encryption refers to a cryptographic system requiring two separate keys, one to encrypt the plaintext, and one to decrypt the ciphertext. Neither key will do both functions. One of these keys is public and the other is kept private. If the encryption key is the one published then the system enables private communication from the public to the decryption key's owner.

Contents

Asymmetric encryption can be used by a protocol or a user in two different ways:

1. The protocol works on an abstract level and does not know the concrete algorithm of the asymmetric encryption. This way the protocol cannot create a specific Plaintext to the encrypt function because it does not know which concrete Plaintext the encrypt function should get. Similarly, the protocol does not know how to treat the Plaintext returned from the decrypt function. In these cases the protocol has a byte array that needs to be encrypted.

2. The protocol knows the concrete algorithm of the asymmetric encryption. This way the protocol knows which Plaintext implementation the encrypt function gets and the decrypt function returns. Therefore, the protocol can be specific and cast the plaintext to the concrete implementation. For example, the protocol knows that it has a DamgardJurikEnc object, so the encrypt function gets a BigIntegerPlaintext and the decrypt function returns a BigIntegerPlaintext. The protocol can create such a plaintext in order to call the encrypt function or cast the returned plaintext from the decrypt function to get the BigInteger value that was encrypted.

The AsymmetricEnc Interface

public interface **`AsymmetricEnc`** extends Cpa, Indistinguishable

General interface for asymmetric encryption. Each class of this family must implement this interface.

Encryption and Decryption

public AsymmetricCiphertext **encrypt** (Plaintext *plainText*)
Encrypts the given plaintext using this asymmetric encryption scheme.

Parameters

- **plainText** – message to encrypt

Throws

- **IllegalArgumentException** – if the given Plaintext doesn't match this encryption type.
- **IllegalStateException** – if no public key was set.

Returns Ciphertext the encrypted plaintext

public Plaintext **decrypt** (AsymmetricCiphertext *cipher*)
Decrypts the given ciphertext using this asymmetric encryption scheme.

Parameters

- **cipher** – ciphertext to decrypt

Throws

- **IllegalArgumentException** – if the given Ciphertext doesn't march this encryption type.
- **KeyException** – if there is no private key

Returns Plaintext the decrypted cipher

Plaintext Manipulation

public Plaintext **generatePlaintext** (byte[] *text*)
Generates a Plaintext suitable for this encryption scheme from the given message.

A Plaintext object is needed in order to use the encrypt function. Each encryption scheme might generate a different type of Plaintext according to what it needs for encryption. The encryption function receives as argument an object of type Plaintext in order to allow a protocol holding the encryption scheme to be oblivious to the exact type of data that needs to be passed for encryption.

Parameters

- **text** – byte array to convert to a Plaintext object.

Throws

- **IllegalArgumentException** – if the given message's length is greater than the maximum.

public byte[] **generateBytesFromPlaintext** (Plaintext *plaintext*)
Generates a byte array from the given plaintext. This function should be used when the user does not know the specific type of the Asymmetric encryption he has, and therefore he is working on byte array.

Parameters

- **plaintext** – to generates byte array from.

Returns the byte array generated from the given plaintext.

public int **getMaxLengthOfByteArrayForPlaintext** ()
Returns the maximum size of the byte array that can be passed to generatePlaintext function. This is the maximum size of a byte array that can be converted to a Plaintext object suitable to this encryption scheme.

Throws

- **NoMaxException** – if this encryption scheme has no limit on the plaintext input.

Returns the maximum size of the byte array that can be passed to generatePlaintext function.

public boolean **hasMaxByteArrayLengthForPlaintext**()
There are some encryption schemes that have a limit of the byte array that can be passed to the generatePlaintext. This function indicates whether or not there is a limit. Its helps the user know if he needs to pass an array with specific length or not.

Returns true if this encryption scheme has a maximum byte array length to generate a plaintext from; false, otherwise.

Key Generation

public KeyPair **generateKey**(AlgorithmParameterSpec *keyParams*)
Generates public and private keys for this asymmetric encryption.

Parameters

- **keyParams** – hold the required parameters to generate the encryption scheme's keys

Throws

- **InvalidParameterSpecException** – if the given parameters don't match this encryption scheme.

Returns KeyPair holding the public and private keys relevant to the encryption scheme

public KeyPair **generateKey**()
Generates public and private keys for this asymmetric encryption.

Returns KeyPair holding the public and private keys

Key Handling

public PublicKey **getPublicKey**()
Returns the PublicKey of this encryption scheme.

This function should not be use to check if the key has been set. To check if the key has been set use isKeySet function.

Throws

- **IllegalStateException** – if no public key was set.

Returns the PublicKey

public boolean **isKeySet**()
Checks if this AsymmetricEnc object has been previously initialized with corresponding keys.

Returns `true` if either the Public Key has been set or the key pair (Public Key, Private Key) has been set; `false` otherwise.

public void **setKey**(PublicKey *publicKey*, PrivateKey *privateKey*)
Sets this asymmetric encryption with public key and private key.

Parameters

- **publicKey** –
- **privateKey** –

Throws

- **InvalidKeyException** – if the given keys don't match this encryption scheme.

public void **setKey**(PublicKey *publicKey*)
Sets this asymmetric encryption with a public key

In this case the encryption object can be used only for encryption.

Parameters

- **publicKey** –

Throws

- **InvalidKeyException** – if the given key doesn't match this encryption scheme.

Reconstruction (from communication channel)

public AsymmetricCiphertext **reconstructCiphertext**(AsymmetricCiphertextSendableData *data*)
Reconstructs a suitable AsymmetricCiphertext from data that was probably obtained via a Channel or any other means of sending data (including serialization).

We emphasize that this is NOT in any way an encryption function, it just receives ENCRYPTED DATA and places it in a ciphertext object.

Parameters

- **data** – contains all the necessary information to construct a suitable ciphertext.

Returns the AsymmetricCiphertext that corresponds to the implementing encryption scheme, for ex: CramerShoupCiphertext

public PrivateKey **reconstructPrivateKey**(KeySendableData *data*)
Reconstructs a suitable PrivateKey from data that was probably obtained via a Channel or any other means of sending data (including serialization).

We emphasize that this function does NOT in any way generate a key, it just receives data and recreates a PrivateKey object.

Parameters

- **data** – a KeySendableData object needed to recreate the original key. The actual type of KeySendableData has to be suitable to the actual encryption scheme used, otherwise it throws an IllegalArgumentException

Returns a new PrivateKey with the data obtained as argument

public PublicKey **reconstructPublicKey**(KeySendableData *data*)
Reconstructs a suitable PublicKey from data that was probably obtained via a Channel or any other means of sending data (including serialization).

We emphasize that this function does NOT in any way generate a key, it just receives data and recreates a PublicKey object.

Parameters

- **data** – a KeySendableData object needed to recreate the original key. The actual type of KeySendableData has to be suitable to the actual encryption scheme used, otherwise it throws an IllegalArgumentException

Returns a new PublicKey with the data obtained as argument

Using the Generic Interface

Sender Usage:

```
//Get an abstract Asymmetric encryption object from somewhere. //Generate a keyPair using the encrypt
KeyPair pair = encryptor.generateKey();

//Publish your public key.
Publish(pair.getPublic());

//Set private key and party2's public key:
encryptor.setKey(party2PublicKey, pair.getPrivate());

//Generate a plaintext suitable for this encryption object using the encryption object.
Plaintext plaintext = encryptor.generatePlaintext(msg);

//Encrypt the plaintext
AsymmetricCiphertext cipher = encryptor.encrypt(plaintext);

//Send cipher and keys to the receiver.
...
```

Receiver Usage:

```
//Get the same asymmetric encryption object as the sender's object. //Generate a keyPair using the en
KeyPair pair = encryptor.generateKey();

//Publish your public key.
Publish(pair.getPublic());

//Set private key and party1's public key:
encryptor.setKey(party1PublicKey, pair.getPrivate());

//Get the ciphertext and decrypt it to get the plaintext.
...

Plaintext plaintext = encryptor.decrypt(cipher);
//Get the plaintext bytes using the encryption object and use it as needed.
byte[] text = encryptor.generatesBytesFromPlaintext(plaintext);
...
```

El Gamal Encryption Scheme

The El Gamal encryption scheme's security is based on the hardness of the decisional Diffie-Hellman (DDH) problem. ElGamal encryption can be defined over any cyclic group G. Its security depends upon the difficulty of a certain problem in G related to computing discrete logarithms. We implement El Gamal over a Dlog Group (G, q, g) where q is the order of group G and g is the generator.

ElGamal encryption scheme can encrypt a group element and a byte array. The general case that accepts a message that should be encrypted usually uses the encryption on a byte array, but in other cases there are protocols that do multiple calculations and might want to keep working on a close group. For those cases we provide encryption on a group element.

In order to allow these two encryption types, we provide two ElGamal concrete classes. One implements the encrypt function on a group element and is called `ScElGamalOnGroupElement`, and the other one implements the encrypt function on a byte array and is called `ScElGamalOnByteArray`.

Note: Note that ElGamal on a groupElement is an asymmetric multiplicative homomorphic encryption, while ElGa-

mal on a ByteArray is not.

ElGamalEnc Interface

public interface **`ElGamalEnc`** extends AsymmetricEnc
General interface for El Gamal encryption scheme. Every concrete implementation of ElGamal should implement this interface. By definition, this encryption scheme is CPA-secure and Indistinguishable.

public AsymmetricCiphertext **`encryptWithGivenRandomValue`** (Plaintext *plaintext*, BigInteger *y*)
Encrypts the given message using ElGamal encryption scheme.

Parameters

- **plaintext** – contains message to encrypt. The given plaintext must match this ElGamal type.

Throws

- **IllegalArgumentException** – if the given Plaintext does not match this ElGamal type.
- **IllegalStateException** – if no public key was set.

Returns Ciphertext containing the encrypted message.

ScElGamalOnByteArray Interface

public class **`ScElGamalOnByteArray`** extends ElGamalAbs
This class performs the El Gamal encryption scheme that perform the encryption on a ByteArray. The general encryption of a message usually uses this type of encryption. By definition, this encryption scheme is CPA-secure and Indistinguishable.

Constructors

public **`ScElGamalOnByteArray`** ()
Default constructor. Uses the default implementations of DlogGroup and SecureRandom.

public **`ScElGamalOnByteArray`** (DlogGroup *dlogGroup*, KeyDerivationFunction *kdf*)
Constructor that gets a DlogGroup and sets it to the underlying group. It lets SCAPI choose and source of randomness.

Parameters

- **dlogGroup** – must be DDH secure.
- **kdf** – a key derivation function.

Throws

- **SecurityLevelException** – if the given dlog group does not have DDH security level.

public **`ScElGamalOnByteArray`** (DlogGroup *dlogGroup*, KeyDerivationFunction *kdf*, SecureRandom *random*)
Constructor that gets a DlogGroup and source of randomness.

Parameters

- **dlogGroup** – must be DDH secure.
- **kdf** – a key derivation function.
- **random** – source of randomness.

Throws

- **SecurityLevelException** – if the given dlog group does not have DDH security level.

Complete Encryption

protected AsymmetricCiphertext **completeEncryption**(GroupElement *c1*, GroupElement *hy*, Plaintext *plaintext*)

Completes the encryption operation.

Parameters

- **plaintext** – contains message to encrypt. MUST be of type ByteArrayPlaintext.

Throws

- **IllegalArgumentException** – if the given Plaintext is not an instance of ByteArrayPlaintext.

Returns Ciphertext of type ElGamalOnByteArrayCiphertext containing the encrypted message.

ScElGamalOnGroupElement Interface

public class **ScElGamalOnGroupElement** extends ElGamalAbs implements AsymMultiplicativeHomomorphicEnc

This class performs the El Gamal encryption scheme that perform the encryption on a GroupElement.

In some cases there are protocols that do multiple calculations and might want to keep working on a close group. For those cases we provide encryption on a group element. By definition, this encryption scheme is CPA-secure and Indistinguishable.

Constructors

public **ScElGamalOnGroupElement**()

Default constructor. Uses the default implementations of DlogGroup, CryptographicHash and SecureRandom.

public **ScElGamalOnGroupElement**(DlogGroup *dlogGroup*)

Constructor that gets a DlogGroup and sets it to the underlying group. It lets SCAPI choose and source of randomness.

Parameters

- **dlogGroup** – must be DDH secure.

Throws

- **SecurityLevelException** –

public **ScElGamalOnGroupElement**(DlogGroup *dlogGroup*, SecureRandom *random*)

Constructor that gets a DlogGroup and source of randomness.

Parameters

- **dlogGroup** – must be DDH secure.
- **random** – source of randomness.

Throws

- **SecurityLevelException** – if the given dlog group does not have DDH security level.

Complete Encryption

protected AsymmetricCiphertext **completeEncryption**(GroupElement *c1*, GroupElement *hy*, Plaintext *plaintext*)

Completes the encryption operation.

Parameters

- **plaintext** – contains message to encrypt. MUST be of type GroupElementPlaintext.

Throws

- **IllegalArgumentException** – if the given Plaintext is not an instance of GroupElementPlaintext.

Returns Ciphertext of type ElGamalOnGroupElementCiphertext containing the encrypted message.

Multiply Ciphertexts (Homomorphic Encryption operation)

public AsymmetricCiphertext **multiply**(AsymmetricCiphertext *cipher1*, AsymmetricCiphertext *cipher2*)

Calculates the ciphertext resulting of multiplying two given ciphertexts. Both ciphertexts have to have been generated with the same public key and DlogGroup as the underlying objects of this ElGamal object.

Throws

- **IllegalArgumentException** – in the following cases: 1. If one or more of the given ciphertexts is not instance of ElGamalOnGroupElementCiphertext. 2. If one or more of the GroupElements in the given ciphertexts is not a member of the underlying DlogGroup of this ElGamal encryption scheme.
- **IllegalStateException** – if no public key was set.

Returns Ciphertext of the multiplication of the plaintexts p1 and p2 where alg.encrypt(p1)=cipher1 and alg.encrypt(p2)=cipher2

Basic Usage

Sender usage:

```
//Create an underlying DlogGroup.
DlogGroup dlog = new MiraclDlogECFp();

//Create an ElGamalOnGroupElement encryption object.
ElGamalEnc elGamal = new ScElGamalOnGroupElement(dlog);

//Generate a keyPair using the ElGamal object.
KeyPair pair = elGamal.generateKey();

//Publish your public key.
Publish(pair.getPublic());

//Set private key and party2's public key:
elGamal.setKey(party2PublicKey, pair.getPrivate());

//Create a GroupElementPlaintext to encrypt and encrypt the plaintext.
Plaintext plaintext = new GroupElementPlaintext(dlog.createRandomElement());
AsymmetricCiphertext cipher = elGamal.encrypt(plaintext);

//Sends cipher to the receiver.
```

Receiver usage:

```
//Create an ElGamal object with the same DlogGroup definition as party1.
//Generate a keyPair using the ElGamal object.
KeyPair pair = elGamal.generateKey();

//Publish your public key.
Publish(pair.getPublic());
```

```
//Set private key and party1's public key:
elGamal.setKey(party1PublicKey, pair.getPrivate());

//Get the ciphertext and decrypt it to get the plaintext. ...
GroupElementPlaintext plaintext = (GroupElementPlaintext)elGamal.decrypt(cipher);

//Get the plaintext element and use it as needed.
GroupElement element = plaintext.getElement(); ...
```

Cramer Shoup DDH Encryption Scheme

The Cramer Shoup encryption scheme's security is based on the hardness of the decisional Diffie-Hellman (DDH) problem, like El Gamal encryption scheme. Cramer Shoup encryption can be defined over any cyclic group G. Its security depends upon the difficulty of a certain problem in G related to computing discrete logarithms.

We implement Cramer Shoup over a Dlog Group (G, q, g) where q is the order of group G and g is the generator.

In contrast to El Gamal, which is extremely malleable, Cramer–Shoup adds other elements to ensure non-malleability even against a resourceful attacker. This non-malleability is achieved through the use of a hash function and additional computations, resulting in a ciphertext which is twice as large as in El Gamal.

Similary to ElGamal, Cramer Shoup encryption scheme can encrypt a group element and a byte array. In order to allow these two encryption types, we provide two Cramer Shoup concrete classes. One implements the encrypt function on a group element and is called `ScCramerShoupDDHOnGroupElement`, and the other one implements the encrypt function on a byte array and is called `ScCramerShoupDDHOnByteArray`.

The CramerShoupDDHEnc Interface

public interface **`CramerShoupDDHEnc`** extends AsymmetricEnc, Cca2

General interface for CramerShoup encryption scheme. Every concrete implementation of CramerShoup encryption should implement this interface. By definition, this encryption scheme is CCA-secure and NonMalleable.

The ScCramerShoupDDHOnByteArray Interface

public class **`ScCramerShoupDDHOnByteArray`** extends CramerShoupAbs

public **`ScCramerShoupDDHOnByteArray`**()

Default constructor. It uses a default Dlog group and CryptographicHash.

public **`ScCramerShoupDDHOnByteArray`**(DlogGroup *dlogGroup*, CryptographicHash *hash*, KeyDerivationFunction *kdf*)

Constructor that lets the user choose the underlying dlog and hash. Uses default implementation of SecureRandom as source of randomness.

Parameters

- **dlogGroup** – underlying DlogGroup to use, it has to have DDH security level
- **hash** – underlying hash to use, has to have CollisionResistant security level

Throws

- **SecurityLevelException** – if the Dlog Group or the Hash function do not meet the required Security Level

public **ScCramerShoupDDHOnByteArray**(DlogGroup *dlogGroup*, CryptographicHash *hash*, KeyDerivationFunction *kdf*, SecureRandom *random*)
Constructor that lets the user choose the underlying dlog, hash and source of randomness.

Parameters

- **dlogGroup** – underlying DlogGroup to use, it has to have DDH security level
- **hash** – underlying hash to use, has to have CollisionResistant security level
- **random** – source of randomness.

Throws

- **SecurityLevelException** – if the Dlog Group or the Hash function do not meet the required Security Level

The ScCramerShoupDDHOnGroupElement Interface

public class **ScCramerShoupDDHOnGroupElement** extends CramerShoupAbs
Concrete class that implement Cramer-Shoup encryption scheme. By definition, this encryption scheme is CCA-secure and NonMalleable.

public **ScCramerShoupDDHOnGroupElement**()
Default constructor. It uses a default Dlog group and CryptographicHash.

public **ScCramerShoupDDHOnGroupElement**(DlogGroup *dlogGroup*, CryptographicHash *hash*)
Constructor that lets the user choose the underlying dlog and hash. Uses default implementation of SecureRandom as source of randomness.

Parameters

- **dlogGroup** – underlying DlogGroup to use, it has to have DDH security level
- **hash** – underlying hash to use, has to have CollisionResistant security level

Throws

- **SecurityLevelException** – if the Dlog Group or the Hash function do not meet the required Security Level

public **ScCramerShoupDDHOnGroupElement**(DlogGroup *dlogGroup*, CryptographicHash *hash*, SecureRandom *random*)
Constructor that lets the user choose the underlying dlog, hash and source of randomness.

Parameters

- **dlogGroup** – underlying DlogGroup to use, it has to have DDH security level
- **hash** – underlying hash to use, has to have CollisionResistant security level
- **random** – source of randomness.

Throws

- **SecurityLevelException** – if the Dlog Group or the Hash function do not meet the required Security Level

Basic Usage

Sender usage:

```
//Create an underlying DlogGroup.
DlogGroup dlog = new MiraclDlogECF2m();

//Create a CramerShoupOnByteArray encryption object.
CramerShoupDDHEnc encryptor = new ScCramerShoupDDHOnByteArray(dlog);

//Generate a keyPair using the CramerShoup object.
KeyPair pair = encryptor.generateKey();

//Publish your public key.
Publish(pair.getPublic());

//Set private key and party2's public key:
encryptor.setKey(party2PublicKey, pair.getPrivate());

//Get a byte[] message to encrypt. Check if the length of the given msg is valid.
if (encryptor.hasMaxByteArrayLengthForPlaintext()){
    if (msg.length>encryptor.getMaxLengthOfByteArrayForPlaintext()) {
        throw new IllegalArgumentException("message too long");
    }
}

//Generate a plaintext suitable to this CramerShoup object.
Plaintext plaintext = encryptor.generatePlaintext(msg);

//Encrypt the plaintext
AsymmetricCiphertext cipher = encrypor.encrypt(plaintext);

//Send cipher and keys to the receiver.
```

Receiver usage:

```
//Create a CramerShoup object with the same DlogGroup definition as party1.
//Generate a keyPair using the CramerShoup object.
KeyPair pair = encryptor.generateKey();

//Publish your public key.
Publish(pair.getPublic());

//Set private key and party1's public key:
encryptor.setKey(party1PublicKey, pair.getPrivate());

//Get the ciphertext and decrypt it to get the plaintext. ...
ByteArrayPlaintext plaintext = ((ByteArrayPlaintext)encryptor).decrypt(cipher);

//Get the plaintext bytes and use it as needed.
byte[] text = plaintext.getText();
```

Damgard Jurik Encryption Scheme

Damgard Jurik is an asymmetric encryption scheme that is based on the Paillier encryption scheme. This encryption scheme is CPA-secure and Indistinguishable.

Interface

public interface **DamgardJurikEnc** extends AsymAdditiveHomomorphicEnc
General interface for DamgardJurik encryption scheme. Every concrete implementation of DamgardJurik encryption should implement this interface. By definition, this encryption scheme is CPA-secure and Indistinguishable.

public AsymmetricCiphertext **reRandomize**(AsymmetricCiphertext *cipher*)
This function takes an encryption of some plaintext (let's call it originalPlaintext) and returns a cipher that "looks" different but it is also an encryption of originalPlaintext.

Parameters

- **cipher** –

Throws

- **IllegalArgumentException** – if the given ciphertext does not match this asymmetric encryption.
- **IllegalStateException** – if no public key was set.

Scapi Implementation

public class **ScDamgardJurikEnc** implements DamgardJurikEnc
Damgard Jurik is an asymmetric encryption scheme based on the Paillier encryption scheme. This encryption scheme is CPA-secure and Indistinguishable.

public **ScDamgardJurikEnc**()
Default constructor. Uses the default implementations of SecureRandom.

public **ScDamgardJurikEnc**(SecureRandom *rnd*)
Constructor that lets the user choose the source of randomness.

Parameters

- **rnd** – source of randomness.

Basic Usage

The code example below is used when the sender and receiver know the specific type of asymmetric encryption object.

Sender code:

```
//Create a DamgardJurik encryption object.
DamgardJurikEnc encryptor = new ScDamgardJurikEnc();

//Generate a keyPair using the DamgardJurik object.
KeyPair pair = encryptor.generateKey(new DJKeyGenParameterSpec(128, 40));

//Publish your public key.
Publish(pair.getPublic());

//Set private key and party2's public key:
encryptor.setKey(party2PublicKey, pair.getPrivate());

//Get the BigInteger value to encrypt, create a BigIntegerPlaintext with it and encrypt the plaintext
...
BigIntegerPlainText plaintext = new BigIntegerPlainText(num);
```

```
AsymmetricCiphertext cipher = encryptor.encrypt(plaintext);

//Send cipher and keys to the receiver.
```

Receiver code:

```
//Create a DamgardJurik object with the same definition as party1.
//Generate a keyPair using the DamgardJurik object.
KeyPair pair = encryptor.generateKey();

//Publish your public key.
Publish(pair.getPublic());

//Set private key and party1's public key:
encryptor.setKey(party1PublicKey, pair.getPrivate());

//Get the ciphertext and decrypt it to get the plaintext. ...
BigIntegerPlainText plaintext = (BigIntegerPlainText)elGamal.decrypt(cipher);

//Get the plaintext element and use it as needed.
BigInteger element = plaintext.getX();
```

RSA Oaep Encryption Scheme

RSA-OAEP is a public-key encryption scheme combining the RSA algorithm with the Optimal Asymmetric Encryption Padding (OAEP) method.

Interface

public interface **RSAOaepEnc** extends AsymmetricEnc, Cca2
: General interface for RSA OAEP encryption scheme. Every concrete implementation of RSA OAEP encryption should implement this interface. By definition, this encryption scheme is CCA-secure and NonMalleable.

Scapi Implementation

public class **BcRSAOaep** extends RSAOaepAbs
: RSA-OAEP encryption scheme based on BC library's implementation. By definition, this encryption scheme is CCA-secure and NonMalleable.

public **BcRSAOaep**()
: Default constructor. Uses default implementation of SecureRandom as source of randomness.

public **BcRSAOaep**(SecureRandom *random*)
: Constructor that lets the user choose the source of randomness.

Parameters

- **random** – source of randomness.

Crypto++ Implementation

public class **CryptoPPRSAOaep** extends RSAOaepAbs
: RSA-OAEP encryption scheme based on Crypto++ library's implementation. By definition, this encryption scheme is CCA-secure and NonMalleable.

public **CryptoPPRSAOaep**()
Default constructor. Uses default implementation of SecureRandom as source of randomness.

public **CryptoPPRSAOaep**(SecureRandom *secureRandom*)
Constructor that lets the user choose the source of randomness.

Parameters

- **secureRandom** – source of randomness.

OpenSSL Implementation

public class **OpenSSLRSAOaep** extends RSAOaepAbs
RSA-OAEP encryption scheme based on OpenSSL library's implementation. By definition, this encryption scheme is CCA-secure and NonMalleable.

public **OpenSSLRSAOaep**()
Default constructor. Uses default implementation of SecureRandom as source of randomness.

public **OpenSSLRSAOaep**(SecureRandom *secureRandom*)
Constructor that lets the user choose the source of randomness.

Parameters

- **secureRandom** – source of randomness.

Basic Usage

Sender code:

```
//Create an RSA encryption object.
RSAOaepEnc encryptor = new CryptoPPRSAOaep();

//Generate a keyPair using the RSAOaep object.
KeyPair pair = encryptor.generateKey(new RSAKeyGenParameterSpec(1024, null));

//Publish your public key.
Publish(pair.getPublic());

//Set private key and party2's public key:
encryptor.setKey(party2PublicKey, pair.getPrivate());

//Get a byte[] message to encrypt. Check if the length of the given msg is valid.
if (encryptor.hasMaxByteArrayLengthForPlaintext()){
    if (msg.length>encryptor.getMaxLengthOfByteArrayForPlaintext()) {
        throw new IllegalArgumentException("message too long");
    }
}

//Generate a plaintext suitable to this RSAOaep object.
Plaintext plaintext = encryptor.generatePlaintext(msg);

//Encrypt the plaintext
AsymmetricCiphertext cipher = encrypor.encrypt(plaintext);

//Send cipher and keys to the receiver.
```

Receiver code:

```
//Create the same RSAOaep object with the same definition as the sender's object.
//Generate a keyPair using the RSAOaep object.
KeyPair pair = encryptor.generateKey();

//Publish your public key.
Publish(pair.getPublic());

//Set private key and party1's public key:
encryptor.setKey(party1PublicKey, pair.getPrivate());

//Get the ciphertext and decrypt it to get the plaintext.
...
ByteArrayPlaintext plaintext = ((ByteArrayPlaintext)encryptor).decrypt(cipher);

//Get the plaintext bytes and use it as needed.
byte[] text = plaintext.getText();
...
```

Digital Signatures

A digital signature is a mathematical scheme for demonstrating the authenticity of a digital message or document. A valid digital signature provides the recipient with a reason to believe that the message was created by a known sender, and that it was not altered in transit.

The Digital Signatures family of classes implements three main functionalities that correspond to the cryptographer's language in which an encryption scheme is composed of three algorithms:

1. Generation of the keys.
2. Signing a message.
3. Verifying a signature with a message.

Contents

The DigitalSignature Interface

public interface **DigitalSignature**

General interface for digital signatures. Each class of this family must implement this interface. A digital signature is a mathematical scheme for demonstrating the authenticity of a digital message or document. A valid digital signature gives a recipient reason to believe that the message was created by a known sender, and that it was not altered in transit.

Sign and Verify

public Signature **sign**(byte[] *msg*, int *offset*, int *length*)

Signs the given message

Parameters

- **msg** – the byte array to sign.
- **offset** – the place in the msg to take the bytes from.
- **length** – the length of the msg.

Throws

- **ArrayIndexOutOfBoundsException** – if the given offset and length are wrong for the given message.
- **KeyException** – if PrivateKey is not set.

Returns the signatures from the msg signing.

public boolean **verify**(Signature *signature*, byte[] *msg*, int *offset*, int *length*)

Verifies the given signature

Parameters

- **signature** – to verify
- **msg** – the byte array to verify the signature with
- **offset** – the place in the msg to take the bytes from
- **length** – the length of the msg

Throws

- **ArrayIndexOutOfBoundsException** – if the given offset and length are wrong for the given message.
- **IllegalArgumentException** – if the given Signature does not match this signature scheme.
- **IllegalStateException** – if no public key was set.

Returns true if the signature is valid. false, otherwise.

Key Generation and Handling

public KeyPair **generateKey**(AlgorithmParameterSpec *keyParams*)

Generates public and private keys for this digital signature.

Parameters

- **keyParams** – hold the required key parameters

Throws

- **InvalidParameterSpecException** – if the given keyParams does not match this signature scheme.

Returns KeyPair holding the public and private keys

public KeyPair **generateKey**()
Generates public and private keys for this digital signature.

Returns KeyPair holding the public and private keys

public PublicKey **getPublicKey**()
Returns the PublicKey of this signature scheme.

This function should not be use to check if the key has been set. To check if the key has been set use isKeySet function.

Throws

- **IllegalStateException** – if no public key was set.

Returns the PublicKey

public boolean **isKeySet**()
Checks if this digital signature object has been given a key already.

Returns `true` if the object has been given a key; `false` otherwise.

public void **setKey**(PublicKey *publicKey*, PrivateKey *privateKey*)
Sets this digital signature with public key and private key.

Parameters

- **publicKey** –
- **privateKey** –

Throws

- **InvalidKeyException** – if the given keys do not match this signature scheme.

public void **setKey**(PublicKey *publicKey*)
Sets this digital signature with a public key.

In this case the signature object can be used only for verification.

Parameters

- **publicKey** –

Throws

- **InvalidKeyException** – if the given key does not match his signature scheme.

RSA Based Digital Signature

The RSABasedSignature Interface

public interface **RSABasedSignature** extends DigitalSignature, UnlimitedTimes
General interface for RSA PSS signature scheme. Every concrete implementation of RSA PSS signature should implement this interface. The RSA PSS (Probabilistic Signature Scheme) is a provably secure way of creating signatures with RSA.

BouncyCastle Implementation

public class **BcRSAPss** extends RSAPssAbs
This class implements the RSA PSS signature scheme, using BC RSAPss implementation. The RSA PSS (Probabilistic Signature Scheme) is a provably secure way of creating signatures with RSA.

public **BcRSAPss**()
Default constructor. uses default implementations of CryptographicHash and SecureRandom.

public **BcRSAPss**(CryptographicHash *hash*, SecureRandom *random*)
Constructor that receives hash and secure random to use.

Parameters

- **hash** – underlying hash to use.
- **random** – secure random to use.

Throws

- **FactoriesException** – if there is no hash with the given name.

Crypto++ Implementation

public class **CryptoPPRSAPss** extends RSAPssAbs
This class implements the RSA PSS signature scheme, using Crypto++ RSAPss implementation. The RSA PSS (Probabilistic Signature Scheme) is a provably secure way of creating signatures with RSA.

public **CryptoPPRSAPss**()
Default constructor. uses default implementation of SecureRandom.

public **CryptoPPRSAPss**(SecureRandom *random*)
Constructor that receives the secure random object to use.

Parameters

- **random** – secure random to use

OpenSSL Implementation

public class **OpenSSLRSAPss** extends RSAPssAbs
This class implements the RSA PSS signature scheme, using OpenSSL RSAPss implementation. The RSA PSS (Probabilistic Signature Scheme) is a provably secure way of creating signatures with RSA.

public **OpenSSLRSAPss**()
Default constructor. uses default implementation of SecureRandom.

public **OpenSSLRSAPss**(SecureRandom *random*)
Constructor that receives the secure random object to use.

Parameters

- **random** – secure random to use

Example of Usage

Sender usage:

```
//Create an RSAPss signature object.
RSAPss signer = new BcRSAPss();

//Generate a keyPair using the RSAPss object.
KeyPair pair = signer.generateKey(new RSAKeyGenParameterSpec(1024, null));

//Generate a keyPair using the signer.
KeyPair pair = signer.generateKey();

//Publish your public key.
Publish(pair.getPublic());

//Set private key and party2's public key:
signer.setKey(party2PublicKey, pair.getPrivate());

//Get a byte[] message to sign, and sign it.
Signature signature= signer.sign(msg, offset, length); //Send signature, msg and keys to the receiver
```

Receiver usage:

```
//Create the same RSAPss object as the sender's object.
//Generate a keyPair using the signer object.
KeyPair pair = signer.generateKey();

//Publish your public key.
Publish(pair.getPublic());

//Set private key and party1's public key:
signer.setKey(party1PublicKey, pair.getPrivate());

//Get the signature and message and verify it.
...

if (!signer.verify(signature, msg, offset, length)) {
    Throw new IllegalArgumentException("the message is not verified!");
}

//Message verified, continue working with it.
...
```

DSA Digital Signature

The DSABasedSignature Interface

public interface **DSABasedSignature** extends DigitalSignature, UnlimitedTimes

General interface for DSA signature scheme. Every concrete implementation of DSA signature should implement this interface.

Scapi Implementation

public class **ScDSA** implements DSABasedSignature

This class implements the DSA signature scheme.

public **ScDSA**()

Default constructor. uses default implementations of CryptographicHash, DlogGroup and SecureRandom.

public **ScDSA**(CryptographicHash *hash*, DlogGroup *dlog*, SecureRandom *random*)
Constructor that receives hash, dlog and secure random to use.

Parameters

- **hash** – underlying hash to use.
- **dlog** – underlying DlogGroup to use.
- **random** – secure random to use.

OpenSSL Implementation

public class **OpenSSLDSA** implements DSABasedSignature
This class implements the DSA signature scheme using OpenSSL library.

public **OpenSSLDSA**()
Default constructor. uses default implementations of DlogGroup.

public **OpenSSLDSA**(DlogGroup *dlog*)
Constructor that receives a dlog to use.

Parameters

- **dlog** – underlying DlogGroup to use.

Example of Usage

Sender usage:

```
//Create a DSA signature object.
DSA signer = new ScDSA(new MiraclDlogECFp());

//Generate a keyPair using the DSA object.
KeyPair pair = signer.generateKey();

//Publish your public key.
Publish(pair.getPublic());

//Set private key and party2's public key:
signer.setKey(party2PublicKey, pair.getPrivate());

//Get a byte[] message to sign, and sign it.
Signature signature= signer.sign(msg, offset, length);

//Send signature, msg and keys to the receiver.
...
```

Receiver usage:

```
//Create the same DSA object as the sender's object.
//Generate a keyPair using the signer object.
KeyPair pair = signer.generateKey();

//Publish your public key.
Publish(pair.getPublic());

//Set private key and party1's public key:
signer.setKey(party1PublicKey, pair.getPrivate());
```

```
//Get the signature and message and verify it.
...

if (!signer.verify(signature, msg, offset, length)) {
    throw new IllegalArgumentException("the message is not verified!");
}

//Message verified, continue working with it.
...
```

Layer 3: Interactive Protocols

The Interactive Protocol layer contains interactive protocols which can be used as a standalone protocols or as building blocks of higher cryptographic schemes. The protocols in this layer are two-party protocols, meaning that there are two participants in the protocol execution when each one has a different role. For example, OT protocol consists of a sender and a receiver, ZK protocol consists of a prover and a verifier, etc. The communication between the parties is done through the SCAPI's Communication Layer.

This layer contains the following components:

Oblivious Transfer Protocols

In Oblivious Transfer, a party called **the sender** has n messages, and a party called **the receiver** has an index i. The receiver wishes to receive the i^{th} message of the sender, without the sender learning i, while the sender wants to ensure that the receiver receives only one of the n messages.

Contents

Class Hierarchy

The general structure of OT protocols contains three components:

- Sender and Receiver interfaces
- Sender and receiver abstract classes
- Sender and receiver concrete classes

Interfaces

Both Sender and Receiver interfaces declare the `transfer()` function, which executes the OT protocol. The `transfer()` function of the sender runs the protocol from the sender's point of view, while the transfer function of the receiver runs the protocol from the receiver's point of view.

Both transfer functions accept two parameters:

- A channel that is used to send and receive messages during the protocol execution.
- An input object that holds the required parameter to the sender/receiver execution.

The input types are `OTSInput` and `OTRInput`. These are marker interfaces for the sender's and receiver's input, respectively. Each concrete implementation may have some different parameters and should implement a dedicated input class that holds them. The transfer functions of the sender and the receiver differ in their return value. While the sender's transfer function returns void, the receiver's transfer function returns `OTROutput`, which is a marker interface. Each concrete OT receiver should implement a dedicated output class that holds the necessary output objects.

The OTSender Interface
public interface **`OTSender`**
public void **`transfer`** (Channel *channel*, OTSInput *input*)

The transfer stage of OT protocol which can be called several times in parallel. The OT implementation support usage of many calls to transfer, with single preprocess execution. This way, one can execute batch OT by creating the OT sender once and call the transfer function for each input couple. In order to enable the parallel calls, each transfer call should use a different channel to send and receive messages. This way the parallel executions of the function will not block each other.

Parameters

- **channel** – each call should get a different one.
- **input** – The parameters given in the input must match the DlogGroup member of this class, which given in the constructor.

Throws

- **ClassNotFoundException** – if there was a problem in the serialization mechanism.
- **IOException** – if there was a problem during the communication.
- **CheatAttemptException** – if the sender suspects that the receiver is trying to cheat.
- **InvalidDlogGroupException** – if the given DlogGRoup is not valid.

The OTReciever Interface
public interface **`OTReceiver`**
public OTROutput **`transfer`** (Channel *channel*, OTRInput *input*)

The transfer stage of OT protocol which can be called several times in parallel. The OT implementation support usage of many calls to transfer, with single preprocess execution. This way, one can execute batch OT by creating the OT receiver once and call the transfer function for each input couple. In order to enable the parallel calls, each transfer call should use a different channel to send and receive messages. This way the parallel executions of the function will not block each other.

Parameters

- **channel** – each call should get a different one.
- **input** – The parameters given in the input must match the DlogGroup member of this class, which given in the constructor.

Throws

- **CheatAttemptException** – if there was a cheat attempt during the execution of the protocol.
- **IOException** – if the send or receive functions failed
- **ClassNotFoundException** – if there was a problem during the serialization mechanism

Returns OTROutput, the output of the protocol.

The Input/Output Interfaces

public interface **`OTSInput`**
: Every OT sender needs inputs during the protocol execution, but every concrete protocol needs different inputs. This interface is a marker interface for OT sender input, where there is an implementing class for each OT protocol.

public interface **`OTRInput`**
: Every OT receiver needs inputs during the protocol execution, but every concrete protocol needs different inputs. This interface is a marker interface for OT receiver input, where there is an implementing class for each OT protocol.

public interface **`OTROutput`**
: Every OT receiver outputs a result in the end of the protocol execution, but every concrete protocol output different data. This interface is a marker interface for OT receiver output, where there is an implementing class for each OT protocol.

Abstract classes

Each concrete OT protocol has abstract classes for both sender and receiver. Both classes implement common behavior of sender and receiver, accordingly. Each of the abstract classes implements the corresponding interface (sender/receiver).

Concrete implementations

As we have already said, each concrete OT implementation should implement dedicated sender and receiver classes. These classes implement the functionalities that are unique for the specific implementation. Most OT protocols can work on two different types of inputs: byte arrays and DlogGroup elements. Each input type should be treated differently, thus we decided to have concrete sender/receiver classes for each input option.

Concrete OT implemented so far are:

- Semi Honest
- Privacy Only
- One Sided Simulation
- Full Simulation
- Full Simulation – ROM
- UC
- Batch Semi Honest
- Batch Semi Honest Extension

Basic Usage

In order to execute the OT protocol, both sender and receiver should be created as separate programs (Usually not on the same machine). The main function in the sender and the receiver is the transfer function, that gets the communication channel between them and input.

Steps in sender creation:

- Given a `Channel` object channel do:
- Create an `OTSender` (for example, `OTSemiHonestDDHOnGroupElementSender`).
- Create input for the sender. Usually, the input for the receiver contains x0 and x1.
- Call the transfer function of the sender with channel and the created input.

```
//Creates the OT sender object.
OTSemiHonestDDHOnGroupElementSender sender = new OTSemiHonestDDHOnGroupElementSender();

//Creates input for the sender.
GroupElement x0 = dlog.createRandomElement();
GroupElement x1 = dlog.createRandomElement();
OTSOnGroupElementInput input = new OTSOnGroupElementInput(x0, x1);

//call the transfer part of the OT protocol
try {
    sender.transfer(channel, input);
} catch (IOException e) {
    // TODO Auto-generated catch block
    e.printStackTrace();
} catch (ClassNotFoundException e) {
    // TODO Auto-generated catch block
    e.printStackTrace();
} catch (CheatAttemptException e) {
    // TODO Auto-generated catch block
    e.printStackTrace();
} catch (InvalidDlogGroupException e) {
    // TODO Auto-generated catch block
    e.printStackTrace();
}
```

Steps in receiver creation:

- Given a `Channel` object channel do:
- Create an `OTReceiver` (for example, `OTSemiHonestDDHOnGroupElementReceiver`).
- Create input for the receiver. Usually, the input for the receiver contains only sigma parameter.
- Call the transfer function of the receiver with channel and the created input.

```
//Creates the OT receiver object.
OTSemiHonestDDHOnGroupElementReceiver receiver = new OTSemiHonestDDHOnGroupElementReceiver();

//Creates input for the receiver.
byte sigma = 1;
OTRBasicInput input = new OTRBasicInput(sigma);

OTROutput output = null;
try {
    output = receiver.transfer(channel, input);
} catch (CheatAttemptException e) {
```

```
    // TODO Auto-generated catch block
    e.printStackTrace();
} catch (IOException e) {
    // TODO Auto-generated catch block
    e.printStackTrace();
} catch (ClassNotFoundException e) {
    // TODO Auto-generated catch block
    e.printStackTrace();
}
//use output...
```

Sigma Protocols

Sigma Protocols are a basic building block for Zero-knowledge proofs, Zero-Knowledge Proofs Of Knowledge and more. A sigma protocol is a 3-round proof, comprised of:

1. A first message from the prover to the verifier
2. A random challenge from the verifier
3. A second message from the prover.

Sigma Protocol can be executed as a standalone protocol or as a building block for another protocol, like Zero Knowledge proofs. As a standalone protocol, Sigma protocol should execute the protocol as is, including the communication between the prover and the verifier. As a building block for other protocols, Sigma protocol should only compute the prover's first and second messages and the verifier's challenge and verification. This is, in other words, the protocol functions without communication between the parties.

To enable both options, there is a separation between the communication part and the actual protocol computations. The general structure of Sigma Protocol contains the following components:

- Prover, Verifier and Simulator generic interfaces.
- Prover and Verifier abstract classes.
- ProverComputation and VerifierComputation classes (Specific to each protocol).

Contents

The Prover Interface

The `SigmaProtocolProver` interface has two modes of operation:

1. Explicit mode - call processFirstMessage() to process the first message and afterwards call processSecondMessage() to process the second message.

2. Implicit mode - Call prove() function that calls the above two functions. This way is more easy to use since the user should not be aware of the order in which the functions must be called.

public interface **SigmaProtocolProver**
General interface for Sigma Protocol prover. Every class that implements it is signed as Sigma Protocol prover. Sigma protocols are a basic building block for zero-knowledge, zero-knowledge proofs of knowledge and more.

A sigma protocol is a 3-round proof, comprised of a first message from the prover to the verifier, a random challenge from the verifier and a second message from the prover. See Hazay-Lindell (chapter 6) for more information.

public void **processFirstMsg**(SigmaProverInput *input*)
Processes the first step of the sigma protocol. It computes the first message and sends it to the verifier.

Parameters

- **input** –

Throws

- **IOException** – if failed to send the message.

public void **processSecondMsg**()
Processes the second step of the sigma protocol. It receives the challenge from the verifier, computes the second message and then sends it to the verifier.

This is a blocking function!

Throws

- **CheatAttemptException** – if the received challenge's length is not equal to the soundness parameter.
- **IOException** – if there was a problem during the communication phase.
- **ClassNotFoundException** – if there was a problem during the serialization mechanism.

public void **prove**(SigmaProverInput *input*)
Runs the proof of this protocol.

This function executes the proof at once by calling the above functions one by one. This function can be called when a user does not want to save time by doing operations in parallel.

Parameters

- **input** –

Throws

- **CheatAttemptException** – if the received challenge's length is not equal to the soundness parameter.
- **IOException** – if there was a problem during the communication phase.
- **ClassNotFoundException** – if there was a problem during the serialization mechanism.

The Verifier Interface

The `SigmaProtocolVerifier` also has two modes of operation:

1. Explicit mode – call sampleChallenge() to sample the challenge, then sendChallenge() to receive the prover's first message and then call processVerify() to receive the prover's second message and verify the proof.
2. Implicit mode - Call verify() function that calls the above three functions. Same as the prove function of the prover, this way is much simpler, since the user should not know the order of the functions.

public interface **SigmaProtocolVerifier**
General interface for Sigma Protocol verifier. Every class that implements it is signed as Sigma Protocol verifier.

public byte[] **getChallenge**()
Returns the sampled challenge.

Returns the challenge.

public boolean **processVerify**(SigmaCommonInput *input*)
Waits to the prover's second message and then verifies the proof. **This is a blocking function!**

Parameters

- **input** –

Throws

- **ClassNotFoundException** – if there was a problem during the serialization mechanism.
- **IOException** – if there was a problem during the communication phase.

Returns true if the proof has been verified; false, otherwise.

public void **sampleChallenge**()
Samples the challenge for this protocol.

public void **sendChallenge**()
Waits for the prover's first message and then sends the chosen challenge to the prover. **This is a blocking function!**

Throws

- **ClassNotFoundException** – if there was a problem during the serialization mechanism.
- **IOException** – if there was a problem during the communication phase.

public void **setChallenge**(byte[] *challenge*)
Sets the given challenge.

Parameters

- **challenge** –

public boolean **verify**(SigmaCommonInput *input*)
Runs the verification of this protocol.

This function executes the verification protocol at once by calling the following functions one by one. This function can be called when a user does not want to save time by doing operations in parallel.

Parameters

- **input** –

Throws

- **ClassNotFoundException** – if there was a problem during the serialization mechanism.
- **IOException** – if there was a problem during the communication phase.

Returns true if the proof has been verified; false, otherwise.

The Simulator Interface

The `SigmaSimulator` has two simulate() functions. Both functions simulate the sigma protocol. The difference between them is the source of the challenge; one function receives the challenge as an input argument, while the

other samples a random challenge. Both simulate functions return `SigmaSimulatorOutput` object that holds the simulated a, e, z.

public interface **`SigmaSimulator`**
General interface for Sigma Protocol Simulator. The simulator is a probabilistic polynomial-time function, that on input x and challenge e outputs a transcript of the form (a, e, z) with the same probability distribution as transcripts between the honest prover and verifier on common input x.

public int **`getSoundnessParam`**()
Returns the soundness parameter for this Sigma simulator.

Returns t soundness parameter

public SigmaSimulatorOutput **`simulate`**(SigmaCommonInput *input*, byte[] *challenge*)
Computes the simulator computation.

Parameters

- **input** –
- **challenge** –

Throws

- **CheatAttemptException** – if the received challenge's length is not equal to the soundness parameter.

Returns the output of the computation - (a, e, z).

public SigmaSimulatorOutput **`simulate`**(SigmaCommonInput *input*)
Chooses random challenge and computes the simulator computation.

Parameters

- **input** –

Returns the output of the computation - (a, e, z).

Computation classes

The classes that operate the **actual** protocol phases implement the `SigmaProverComputation` and `SigmaVerifierComputation` interfaces. SigmaProverComputation computes the prover's messages and SigmaVerifierComputation computes the verifier's challenge and verification. Each operation is done in a dedicated function.

In case that Sigma Protocol is used as a building block, the protocol which uses it will hold an instance of SigmaProverComputation or SigmaVerifierComputation and will call the required function. Each concrete sigma protocol should implement the computation interfaces.

SigmaProverComputation

public interface **`SigmaProverComputation`**
This interface manages the mathematical calculations of the prover side in the sigma protocol. It samples random values and computes the messages.

public SigmaProtocolMsg **`computeFirstMsg`**(SigmaProverInput *input*)
Computes the first message of the sigma protocol.

Parameters

- **input** –

public SigmaProtocolMsg **computeSecondMsg**(byte[] *challenge*)
Computes the second message of the sigma protocol.

Throws

- **CheatAttemptException** – if the received challenge's length is not equal to the soundness parameter.

SigmaVerifierComputation

public interface **SigmaVerifierComputation**
This interface manages the mathematical calculations of the verifier side in the sigma protocol. It samples random challenge and verifies the proof.

public void **sampleChallenge**()
Samples the challenge for this protocol.

public void **setChallenge**(byte[] *challenge*)
Sets the given challenge.

Parameters

- **challenge** –

public byte[] **getChallenge**()
Returns the sampled challenge.

Returns the challenge.

public boolean **verify**(SigmaCommonInput *input*, SigmaProtocolMsg *a*, SigmaProtocolMsg *z*)
Verifies the proof.

Parameters

- **input** –

Returns true if the proof has been verified; false, otherwise.

Supported Protocols

Concrete Sigma protocols implemented so far are:

- Dlog
- DH
- Extended DH
- Pedersen commitment knowledge
- Pedersen committed value
- El Gamal commitment knowledge
- El Gamal committed value
- El Gamal private key
- El Gamal encrypted value
- Cramer-Shoup encrypted value
- Damgard-Jurik encrypted zero

- Damgard-Jurik encrypted value
- Damgard-Jurik product
- AND (of multiple statements)
- OR of two statements
- OR of multiple statements

Example of Usage

Steps in prover creation:

- Given a `Channel` object channel and input for the concrete Sigma protocol prover (In the example below, x and h) do:
  - Create a `SigmaProverComputation` (for example, `SigmaDlogProverComputation`).
  - Create a `SigmaProtocolProver` with channel and the proverComputation.
  - Create input object for the prover.
  - Call the `prove()` function of the prover with the input.

Prover code example:

```
//Creates the dlog group.
DlogGroup dlog = null;
try {
    //use the koblitz curve.
    dlog = new MiraclDlogECF2m("K-233");
} catch (FactoriesException e1) {
    // TODO Auto-generated catch block
    e1.printStackTrace();
}

//Creates sigma prover computation.
SigmaProverComputation proverComputation = new SigmaDlogProverComputation(dlog, t, new SecureRandom()

//Create Sigma Prover with the given SigmaProverComputation.
SigmaProver prover = new SigmaProver(channel, proverComputation);

//Creates input for the prover.
SigmaProverInput input = new SigmaDlogProverInput(h, w);

//Calls the prove function of the prover.
prover.prove(input);
```

Steps in verifier creation:

- Given a `Channel` object channel and input for the concrete Sigma protocol verifier (In the example below, h) do:
  - Create a `SigmaVerifierComputation` (for example, `SigmaDlogVerifierComputation`).
  - Create a `SigmaProtocolVerifier` with channel and verifierComputation.
  - Create input object for the verifier.
  - Call the `verify()` function of the verifier with the input.

Verifier code example:

```
//Creates the dlog group
DlogGroup dlog = null;
try {
    //use the koblitz curve
    dlog = new MiraclDlogECF2m("K-233");
} catch (FactoriesException e1) {
    // TODO Auto-generated catch block
    e1.printStackTrace();
}

//Creates sigma verifier computation.
SigmaVerifierComputation verifierComputation = new SigmaDlogVerifierComputation(dlog, t, new SecureRa

//Creates Sigma verifier with the given SigmaVerifierComputation.
SigmaVerifier verifier = new SigmaVerifier(channel, verifierComputation);

// Creates input for the verifier.
SigmaCommonInput input = new SigmaDlogCommonInput(h);

//Calls the verify function of the verifier.
verifier.verify(input);
```

Zero Knowledge Proofs and Zero Knowledge Proofs of Knowledge

A **zero-knowledge proof** or a zero-knowledge protocol is a method by which one party (the prover) can prove to another party (the verifier) that a given statement is true, without conveying any additional information apart from the fact that the statement is indeed true. A **zero-knowledge proof of knowledge (ZKPOK)** is a sub case of zero knowledge proofs, in which the prover proves to the verifier that he knows how to prove a statement, without actually proving it.

Contents

Zero Knowledge Interfaces

ZKProver

The `ZKProver` interface declares the `prove()` function that accepts an input and runs the ZK proof. The input type is `ZKProverInput`, which is a marker interface. Every concrete protocol should have a dedicated input class that implements it.

public interface **`ZKProver`**

A zero-knowledge proof or zero-knowledge protocol is a method by which one party (the prover) can prove to

another party (the verifier) that a given statement is true, without conveying any additional information apart from the fact that the statement is indeed true.

This interface is a general interface that simulates the prover side of the Zero Knowledge proof. Every class that implements it is signed as Zero Knowledge prover.

public void **prove** (ZKProverInput *input*)
Runs the prover side of the Zero Knowledge proof.

Parameters

- **input** – holds necessary values to the proof calculations.

Throws

- **CheatAttemptException** – if the prover suspects the verifier is trying to cheat.
- **IOException** – if there was a problem during the communication.
- **ClassNotFoundException** – if there was a problem during the serialization mechanism.
- **CommitValueException** – can occur when using ElGamal commitment scheme.

ZKVerifier

The `ZKVerifier` interface declares the `verify()` function that accepts an input and runs the ZK proof verification. The input type is `ZKCommonInput`, which is a marker interface of inputs that are common for the prover and the verifier. Every concrete protocol should have a dedicated input class that implements it.

public interface **ZKVerifier**
A zero-knowledge proof or zero-knowledge protocol is a method by which one party (the prover) can prove to another party (the verifier) that a given statement is true, without conveying any additional information apart from the fact that the statement is indeed true.

This interface is a general interface that simulates the verifier side of the Zero Knowledge proof. Every class that implements it is signed as Zero Knowledge verifier.

public boolean **verify** (ZKCommonInput *input*)
Runs the verifier side of the Zero Knowledge proof.

Parameters

- **input** – holds necessary values to the varification calculations.

Throws

- **CheatAttemptException** – if the prover suspects the verifier is trying to cheat.
- **IOException** – if there was a problem during the communication.
- **ClassNotFoundException** – if there was a problem during the serialization mechanism.
- **CommitValueException** – can occur when using ElGamal commitment scheme.

Returns true if the proof was verified; false, otherwise.

ZKProverInput

public interface **ZKProverInput**
Marker interface. Each concrete ZK prover's input class should implement this interface.

ZKCommonInput

public interface **ZKCommonInput**
: This interface is a marker interface for Zero Knowledge input, where there is an implementing class for each concrete Zero Knowledge protocol.

Zero Knowledge Proof of Knowledge Interfaces

ZKPOKProver and ZKPOKVerifier are marker interfaces that extend the ZKProver and ZKVerifier interfaces. ZKPOK concrete protocol should implement these marker interfaces instead of the general ZK interfaces.

public interface **ZKPOKProver** extends ZKProver
: This interface is a general interface that simulates the prover side of the Zero Knowledge proof of knowledge. Every class that implements it is signed as ZKPOK prover.

public interface **ZKPOKVerifier** extends ZKVerifier
: This interface is a general interface that simulates the verifier side of the Zero Knowledge proof of knowledge. Every class that implements it is signed as ZKPOK verifier.

Implemented Protocols

Concrete Zero Knowledge protocols implemented so far are:

- Zero Knowledge from any sigma protocol
- Zero Knowledge Proof of Knowledge from any sigma protocol (currently implemented using Pedersen Commitment scheme)
- Zero Knowledge Proof of Knowledge from any sigma protocol Fiat Shamir (Random Oracle Model)

Example of Usage

Steps in prover creation:

- Given a Channel object channel and input for the underlying SigmaProverComputation (in the following case, h and x) do:
  - Create a SigmaProverComputation (for example, SigmaDlogProverComputation).
  - Create a ZKProver with channel and the proverComputation (ForExample, ZKFromSigmaProver).
  - Create input object for the prover.
  - Call the prove function of the prover with the input.

Prover code example:

```
try {
    //create the ZK prover
    DlogGroup dlog = new MiraclDlogECF2m("K-233");
    ZKProver prover = new ZKFromSigmaProver(channel, new SigmaDlogProverComputation(dlog, 40, new Sec

    //create the input for the prover
    SigmaDlogProverInput input = new SigmaDlogProverInput(h, x);

    //Call prove function
    prover.prove(input);
```

```
} catch (IllegalArgumentException e) {
    // TODO Auto-generated catch block
    e.printStackTrace();
} catch (IOException e) {
    // TODO Auto-generated catch block
    e.printStackTrace();
} catch (CheatAttemptException e) {
    // TODO Auto-generated catch block
    e.printStackTrace();
} catch (ClassNotFoundException e) {
    // TODO Auto-generated catch block
    e.printStackTrace();
} catch (CommitValueException e) {
    // TODO Auto-generated catch block
    e.printStackTrace();
}
```

Steps in verifier creation:

- Given a Channel object channel and input for the underlying SigmaVerifierComputation (In the example below, h) do:
  - Create a SigmaVerifierComputation (for example, SigmaDlogVerifierComputation).
  - Create a ZKVerifier with channel and verifierComputation (For example, ZKFromSigmaVerifier).
  - Create input object for the verifier.
  - Call the verify function of the verifier with the input.

Verifier code example:

```
try {
    //create the ZK verifier
    DlogGroup dlog = new MiraclDlogECF2m("K-233");
    ZKVerifier verifier = new ZKFromSigmaVerifier(channel, new SigmaDlogVerifierComputation(dlog, 40,

    //create the input for the verifier
    SigmaDlogCommonInput input = new SigmaDlogCommonInput(h);
    //Call verify function
    System.out.println(verifier.verify(input));

} catch (IllegalArgumentException e) {
    // TODO Auto-generated catch block
    e.printStackTrace();
} catch (IOException e) {
    // TODO Auto-generated catch block
    e.printStackTrace();
} catch (CheatAttemptException e) {
    // TODO Auto-generated catch block
    e.printStackTrace();
} catch (ClassNotFoundException e) {
    // TODO Auto-generated catch block
    e.printStackTrace();
} catch (CommitValueException e) {
    // TODO Auto-generated catch block
    e.printStackTrace();
} catch (InvalidDlogGroupException e) {
    // TODO Auto-generated catch block
```

```
    e.printStackTrace();
}
```

Commitment Schemes

A commitment scheme allows one to commit to a chosen value (or a chosen statement) while keeping it hidden from others, with the ability to reveal the committed value later. There exist some commitment schemes that can be proven by ZK protocols.

Contents

The Committer Interface

public interface **`CmtCommitter`**

This the general interface of the Committer side of a Commitment Scheme. A commitment scheme has a commitment phase in which the committer send the commitment to the Receiver, and a decommitment phase in which the the Committer sends the decommitment to the Receiver.

Commit and Decommit

public void **`commit`**(CmtCommitValue *input*, long *id*)

This function is the heart of the commitment phase from the Committer's point of view.

Parameters

- **input** – The value that the committer commits about.
- **id** – Unique value attached to the input to keep track of the commitments in the case that many commitments are performed one after the other without decommiting them yet.

Throws

- **IOException** – if there is any problem at the communication level

public void **`decommit`**(long *id*)

This function is the heart of the decommitment phase from the Committer's point of view.

Parameters

- **id** – Unique value used to identify which previously committed value needs to be decommitted now.

Throws

- **CheatAttemptException** – if the committer suspects that the receiver attempted cheating
- **IOException** – if there is any problem at the communication level
- **ClassNotFoundException** – if the commitment cannot be serialized
- **CommitValueException** – if the commit value does not match the implementing commitment.

Conversion to and from CmtCommitValue

public byte[] **generateBytesFromCommitValue**(CmtCommitValue *value*)
This function converts the given commit value to a byte array.

Parameters

- **value** – to get its bytes.

Returns the generated bytes.

public CmtCommitValue **generateCommitValue**(byte[] *x*)
This function wraps the raw data x with a suitable CommitValue instance according to the actual implementaion.

Parameters

- **x** – array to convert into a commitValue.

Throws

- **CommitValueException** – if the commit value does not match the implementing commitment

Returns the created CommitValue.

Inner state functions

public CmtCommitmentPhaseValues **getCommitmentPhaseValues**(long *id*)
This function returns the values calculated during the commit phase for a specific commitment. This function is used for protocols that need values of the commitment, like ZK protocols during proofs on the commitment. We recommended not to call this function from somewhere else.

Parameters

- **id** – of the specific commitment

Returns values calculated during the commit phase

public Object[] **getPreProcessValues**()
This function returns the values calculated during the preprocess phase. This function is used for protocols that need values of the commitment, like ZK protocols during proofs on the commitment. We recommended not to call this function from somewhere else.

Returns values calculated during the preprocess phase

public CmtCommitValue **sampleRandomCommitValue**()
This function samples random commit value to commit on.

Returns the sampled commit value.

The Receiver Interface

public interface **CmtReceiver**

This the general interface of the Receiver side of a Commitment Scheme. A commitment scheme has a commitment phase in which the Receiver waits for the commitment sent by the Committer; and a decommitment phase in which the Receiver waits for the decommitment sent by the Committer and checks whether to accept or reject the decommitment.

Receive Commitment and Decommitment

public CmtRCommitPhaseOutput **receiveCommitment** ()

This function is the heart of the commitment phase from the Receiver's point of view.

Throws

- **ClassNotFoundException** – if the commitment received cannot be deserialized
- **IOException** – if there is any problem at the communication level

Returns the id of the commitment and some other information if necessary according to the implementing class.

public CmtCommitValue **receiveDecommitment** (long *id*)

This function is the heart of the decommitment phase from the Receiver's point of view.

Parameters

- **id** – wait for a specific message according to this id

Throws

- **CheatAttemptException** – if there is an error that could have been caused by a cheating attempt
- **ClassNotFoundException** – if the decommitment received cannot be deserialized
- **IOException** – if there is any problem at the communication level.
- **CommitValueException** – if the commit value does not match the implementing commitment.

Returns the commitment

Conversion to and from CmtCommitValue

public byte[] **generateBytesFromCommitValue** (CmtCommitValue *value*)

This function converts the given commit value to a byte array.

Parameters

- **value** – to get its bytes.

Returns the generated bytes.

Inner state functions

public Object **getCommitmentPhaseValues** (long *id*)

Return the intermediate values used during the commitment phase.

Parameters

- **id** – get the commitment values according to this id.

Returns a general array of Objects.

public Object[] **getPreProcessedValues**()

Return the values used during the pre-process phase (usually upon construction). Since these values vary between the different implementations this function returns a general array of Objects.

Returns a general array of Objects

Implementations in Scapi

Each concrete commitment protocol should have committer and receiver classes that implement the `CmtCommitter` and `CmtReceiver` interfaces mentioned above or the `CmtCommitterWithProofs` and `CmtReceiverWithProofs`, in case the scheme can be proven.

Concrete Commitments protocols implemented so far are: * Pedersen commitment * Pedersen Hash commitment * Pedersen Trapdoor commitment * El Gamal commitment * El Gamal Hash commitment * Simple Hash commitment * Equivoqal commitments

Example of Usage

Commitment protocol has two sides: committer and receiver. In order to execute the commitment protocol, both committer and receiver should be created as separate programs (Usually not on the same machine).

Steps in committer creation:

- Given a `Channel` object ch do:
  - Create a `CmtCommitter` (for example, `CmtPedersenCommitter`).
  - Create an instance of the concrete `CommitValue` that suits the commitment scheme (This can be done by calling the function `generateCommitValue(byte[])`.
  - Call the `commit()` function of the committer with the committed value and id.
  - Call the `decommit()` function of the committer with the same id sent to the `commit()` function.

Code example:

```
try {
    //create the committer
    DlogGroup dlog = new MiraclDlogECF2m("K-233");
    CmtCommitter committer = new CmtPedersenCommitter(ch, dlog, new SecureRandom());

    //generate CommitValue from string
    CmtCommitValue val = committer.generateCommitValue(new String("commit this string!").getBytes());

    //Commit on the commit value with id 2
    committer.commit(val, 2);

    //decommit id 2
    committer.decommit(2);

} catch (SecurityLevelException e) {
    // TODO Auto-generated catch block
    e.printStackTrace();
} catch (InvalidDlogGroupException e) {
    // TODO Auto-generated catch block
    e.printStackTrace();
```

```
} catch (ClassNotFoundException e) {
    // TODO Auto-generated catch block
    e.printStackTrace();
} catch (IOException e) {
    // TODO Auto-generated catch block
    e.printStackTrace();
} catch (CheatAttemptException e) {
    // TODO Auto-generated catch block
    e.printStackTrace();
} catch (CommitValueException e) {
    // TODO Auto-generated catch block
    e.printStackTrace();
}
```

Steps in receiver creation:

- Given a `Channel` object ch do:
  - Create a `CmtReceiver (for example, :java:ref:`CmtPedersenReceiver`).
  - Call the `receiverCommitment()` function of the receiver.
  - Call the `receiveDecommitment()` function of the receiver with the id given in the output of the `receiverCommitment()` function.
  - The `CommitValue` returned from the `receiveDecommitment()` can be converted to bytes using the `generateBytesFromCommitValue()` function of the receiver.

Code example:

```
try {
    //create the receiver
    dlog = new MiraclDlogECF2m("K-233");
    CmtReceiver receiver = new CmtPedersenReceiver(ch, dlog, new SecureRandom());

    //Receive the commitment on the commit value
    CmtRCommitPhaseOutput output = receiver.receiveCommitment();

    //Receive the decommit
    CmtCommitValue val = receiver.receiveDecommitment(output.getCommitmentId());

    //Convert the commitValue to bytes.
    String committedString = new String(receiver.generateBytesFromCommitValue(val));

    System.out.println(committedString);

} catch (IllegalArgumentException e) {
    // TODO Auto-generated catch block
    e.printStackTrace();
} catch (IOException e) {
    // TODO Auto-generated catch block
    e.printStackTrace();
} catch (SecurityLevelException e) {
    // TODO Auto-generated catch block
    e.printStackTrace();
} catch (InvalidDlogGroupException e) {
    // TODO Auto-generated catch block
    e.printStackTrace();
} catch (ClassNotFoundException e) {
    // TODO Auto-generated catch block
```

```
    e.printStackTrace();
} catch (CommitValueException e) {
    // TODO Auto-generated catch block
    e.printStackTrace();
} catch (CheatAttemptException e) {
    // TODO Auto-generated catch block
    e.printStackTrace();
}
```

Coin Tossing

The basic case of coin tossing is the practice of throwing a coin in the air to choose between two alternatives, sometimes to resolve a dispute between two parties. The "coin" in our implementation can be various data types, like a bit or a byte array. Each implementation achieves different security levels.

The general structure of Coin Tossing protocols contains two levels:

- PartyOne and PartyTwo interfaces
- PartyOne and PartyTwo concrete classes for each coin tossing implementation.

Contents

Coin Tossing Interfaces

The only function in the coin tossing interfaces (both party one, and party two) is the `toss()` function. This function executes the coin tossing protocol and returns a `CTOutput` object. `CTOutput` is a marker interface for the tossed "coin". For each concrete coin type we should implement a dedicated class which will be returned. For example, Blum protocol tosses a single bit, therefore, `CTBlumPartyOne` and `CTBlumPartyTwo` return `CTBitOutput` object as the output of the toss function.

CTPartyOne

public interface **`CTPartyOne`**

Coin tossing is the practice of throwing a coin in the air to choose between two alternatives, sometimes to resolve a dispute between two parties. This is a general interface plays as party one of a coin tossing protocol. Each concrete party one class of a coin tossing protocol should implement this interface.

public CTOutput **`toss`**`()`

Executes party one role of this coin tossing protocol.

Throws

- **CheatAttemptException** – if party one suspects that party two is trying to cheat.
- **ClassNotFoundException** – if there was a problem in the serialization mechanism

- **IOException** – can occur in the commit phase.
- **CommitValueException** – can occur in case the protocol uses an ElGamal committer.

Returns CTOutput contains the tossed "coin".

CTPartyTwo

public interface **CTPartyTwo**

Coin tossing is the practice of throwing a coin in the air to choose between two alternatives, sometimes to resolve a dispute between two parties. This is a general interface plays as party two of a coin tossing protocol. Each concrete party two class of a coin tossing protocol should implement this interface.

public CTOutput **toss**()

Executes party two role of this coin tossing protocol.

Throws

- **CheatAttemptException** – if party one suspects that party two is trying to cheat.
- **ClassNotFoundException** – if there was a problem in the serialization mechanism
- **IOException** – can occur in the commit phase.
- **CommitValueException** – can occur in case the protocol uses an ElGamal receiver.

Returns CTOutput contains the tossed "coin".

CTOutput

public interface **CTOutput**

Each coin tossing protocol outputs different "coin". It can be a single bit, a string, etc. Each concrete output class should implement this interface.

public Object **getOutput**()

Returns the output of the coin tossing protocol. The tossed value of the Coin Tossing protocol can vary. Returns Object instance to enable any return value.

Returns the tossed output.

Implementations in Scapi

Concrete Coin Tossing protocols implemented so far are:

- Coin Tossing of a single bit (Blum)
- Coin Tossing of a String
- Semi-Simulatable Coin-Tossing of a String

SCAPI in C++ (Beta)

Until recently SCAPI was a java-only library that in some cases wrapped native elements using JNI. SCAPI is now supported and maintained in C++ version as well. Roughly speacking, Java-SCAPI is great for fast development of application and for POCing cryptographic protocols. However, when performance is a main concern, a c++ implementation might be more suitable.

This is still "work in progress" and should be considered as beta. There are few modules that exist in the java version but were still not ported to the C++ version. The SCAPI team is working these days on expending the c++ implementation further.

Installing SCAPI - Linux

The following explains how to install libscapi (SCAPI c++) on Ubuntu. For other Linux variants it should work as well with the appropriate adjustments.

Prerequisites

Update and install git, gcc, gmp, and open ssl. On Ubuntu environment is should look like:

```
$ sudo apt-get update
$ sudo apt-get install -y git build-essential
$ sudo apt-get install -y libssl-ocaml-dev libssl-dev
$ sudo apt-get install -y libgmp3-dev
```

Download and install boost (the last step might take some time. patience):

```
$ wget -O boost_1_60_0.tar.bz2 http://sourceforge.net/projects/boost/files/boost/1.60.0/boost_1_60_0
$ tar --bzip2 -xf boost_1_60_0.tar.bz2
$ cd boost_1_60_0
$  ./bootstrap.sh
$  ./b2
```

More details about boost here: http://www.boost.org/doc/libs/1_60_0/more/getting_started/unix-variants.html

Building libscapi and publishing libs

Download and build libscapi:

```
$ cd ~
$ git clone https://github.com/cryptobiu/libscapi.git
$ cd libscapi
$ make
```

Publish new libs:

```
$ sudo ldconfig ~/boost_1_60_0/stage/lib/ ~/libscapi/install/lib/
```

Building and Running the Tests

In order to build and run tests:

```
$ cd ~/libscapi/test
$ make
$ ./tests.exe
```

Samples

Build and run the samples program:

```
$ cd ~/libscapi/samples
$ make
```

In order to see all available samples:

```
$ ./libscapi_example.exe
```

In order to run simple examples (dlog or sha1):

```
$ ./libscapi_example.exe dlog
$ ./libscapi_example.exe sha1
```

You should get some print outs if everything works well.

In order to run the CommExample. Open two terminals. In the first run:

```
$ ./libscapi_example.exe comm 1 Comm/CommConfig.txt
```

And in the other run:

```
$ ./libscapi_example.exe comm 2 Comm/CommConfig.txt
```

In order to run Semi-honset YAO, run in the first terminal:

```
$ ./libscapi_example.exe yao 1 Yao/YaoConfig.txt
```

And in the second:

```
$ ./libscapi_example.exe yao 2 Yao/YaoConfig.txt
```

Finally in order to run the Sigma example - in the first terminal run:

```
$ ./libscapi_example.exe sigma 1 SigmaPrototocls/SigmaConfig.txt
```

And in the second terminal:

```
$ ./libscapi_example.exe sigma 1 SigmaPrototocls/SigmaConfig.txt
```

You can edit the config file in order to play with the different params in all examples.

Installing SCAPI - Windows

Installing scapi on windows will require git client and Visual Studio IDE. We tested it with VS2015.

Prerequisites:

1. Download and install open ssl for windows: https://slproweb.com/products/Win32OpenSSL.html (choose 64bit not light)
2. Download and install boost binaries for windos: https://sourceforge.net/projects/boost/files/boost-binaries/1.60.0/ choose 64 bit version 14

The windows solutions assume that boost is installed at `C:\local\boost_1_60_0` and that OpenSSL at: `C:\OpenSSL-Win64`

Pull libscapi from GitHub. For convenient we will assume that libscapi is located at: `c:\code\scapi\libscapi`. If it is located somewhere eles then the following paths should be adjusted accrodingly.

1. **Build Miracl for windows 64:**
    (a) Open solution MiraclWin64.sln at: `C:\code\libscapi\lib\MiraclCompilation`

(b) Build the solution once for debug and once for release

2. **Build OTExtension for window 64:**
   (a) Open solution OTExtension.sln at `C:\code\libscapi\lib\OTExtension\Win64-sln`
   (b) Build solution once for debug and once for release
3. **Build GarbledCircuit project**
   (a) Open solution ScGarbledCircuitWin64.sln at `C:\code\libscapi\lib\ScGarbledCircuit\ScGarbledCi`
   (b) Build solution once for debug and once for release
4. **Build the NTL solution:**
   (a) Open solution NTL-WIN64.sln at `C:\code\libscapi\lib\NTL\windows\NTL-WIN64`
   (b) Build solution once for debug and once for release
5. **Build Scapi Solution including examples and test:**
   (a) Open solution ScapiCpp.sln at `C:\code\libscapi\windows-solutions\scapi-sln`
   (b) Build solution once for debug and once for release - (as needed)
6. **Run tests.**
   (a) Go to `C:\code\libscapi\windows-solutions\scapi-sln\x64\debug`
   (b) run ./scapi_tests.exe and make sure all is green
7. **Run example:**
   (a) open two terminals
   (b) in both of them go to: `C:\code\libscapi\windows-solutions\scapi-sln\x64\debug`
   (c) To see available samples run `libscapi_examples.exe`
   (d) Follow instruction of how to run the different samples as exaplained in the linux section
   (e) You can edit the different config file to play with the paramaters

Further Reading

For further reading - refer to the extensive Java documentation. The c++ implementation usally follows the same concept except when language specific need required some change.

License

ACTION OF CONTRACT, TORT OR OTHERWISE, ARISING FROM, OUT OF OR IN CONNECTION WITH THE SOFTWARE OR THE USE OR OTHER DEALINGS IN THE SOFTWARE.

We request that any publication and/or code referring to and/or based on SCAPI contain an appropriate citation to SCAPI, including a reference to http://crypto.biu.ac.il/scapi.

SCAPI uses other open source libraries: Crypto++, Miracl, NTL, OpenSSL, OtExtension and Bouncy Castle. *Please see these projects for any further licensing issues.*

If you can't find what you are looking for, have a look at the index or try to use the search:

- *genindex*
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