# Assignment 1
# Brute Force Attack Estimation

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Code repository: COMP522-Assignment 2

## 1 Comparison of methods for message authentication

### 1.1 Hash-functions

Hash functions are used in order to attempt to ensure to both the sender and the receiver that a message is authentic and has not been manipulated or interfered with in any way. Hash functions are typically used when a secret is not shared between the sender and the receiver.
The process of using a hash function is the following:
- An unencrypted message is sent from the sender to the receiver with a tag (hash) which has been generated by the sender.
- The receiver then received the message and the tag and in order to establish if the message has been tampered with they generate their own hash using the message from the sender.
- Once the receiver has generated their own hash they then compare the hash they generated to the hash they received as the tag. If the hash generated by the receiver doesn't match the tag hash then the message has been tampered with and the contents cant be trusted however if the hash and tag hash do match then the message hasnt been manipulated and can be trusted to be original.

Hash functions are typically referred to as one way hashes. This is because it is easy to generate a hash using a message however it is very difficult to generate the message from the hash. The tag hash that is generated using a hash function algorithm e.g. the SHA1 typically produces a fixed length hash which is not dependent on the size of the message being sent.

*Appendix A* is an example of the SHA1 hash function which takes a string input and digests the input using the SHA1 algorithm to produce a byte array hash.
Input = "This is a string"
Output in the form of a hash using the SHA1 algorithm = f72017485fbf6423499baf9b240daa14f5f095a1

The advantage of hash functions are that they are very simple to compute and are an effective way of telling if a message is genuine or if it has been manipulated.

The disadvantage of Hash functions are that since the message is unencrypted, the content of the message is not secure so anyone can read the original message and as long as they dont change the hash then the hash will still match the original message. The hash is also easy to replace so the message could be read and manipulated by an illicit party who could then generate a new hash tag and send the message on to the original recipient with a new content and a new hash which will match when they attempt to compare generated hashes. Hash functions also do not satisfy the weak and strong collision policys so it is possible you could generate a duplicate hash. A further issue with the SHA1 algorithm has been identified that it has a mathematical weakness which makes the outputs of the algorithm vulnerable to decryption.

### 1.2 RSA + SHA1 method

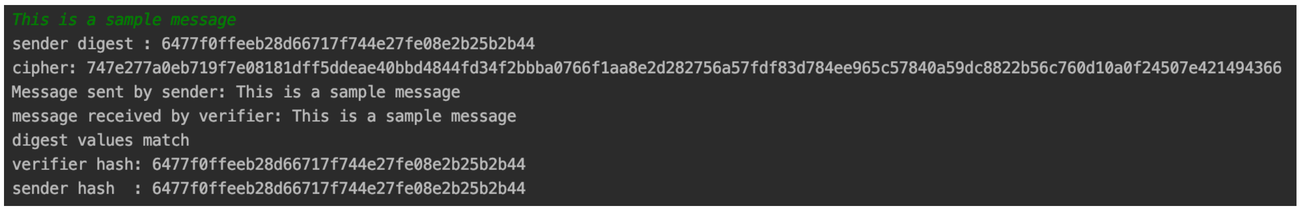
The methodology discussed in this section is the combination of the hashing mechanism SHA1 with the RSA algorithm which combines the hashing algorithm discussed previously in *Section 1.a.* and demonstrated in *Appendix A* together with the use of public and private keys in order to create a more secure message sharing methodology.

The combination of RSA and SHA1 hashing allows a sender (*Appendix B*) to generate a hash using a hash algorithm e.g. SHA1. Then this hash tag is encrypted using a private key which has been generated as part of the key pair to produce a ciphertext.

The ciphertext, plain text message and corresponding public key is sent to the verifier.

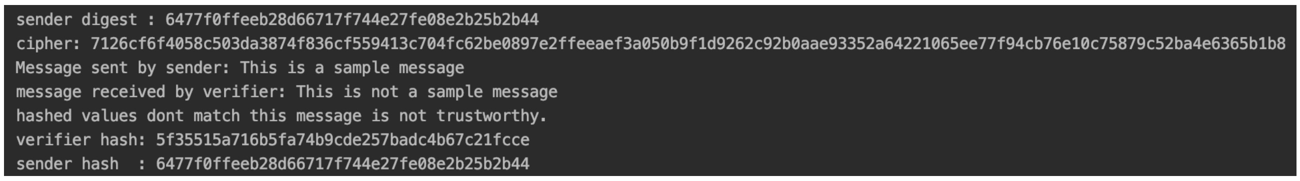
The verifier then uses the same hashing algorithm and the plain text message to generate their own hash. They also decrypt the ciphertext using the public key provided in the message. Once the verifier has their own hash and has the decrypted hash they can compare the values to see if they match. As in Hash functions if the hash tags do not match then the message is untrustworthy and needs to be discarded.

An example of how a tampered with message can be detected can be created using *Appendix B* and *Appendix C*. In the experiment below I have generated a message containing the string "This is a sample message" which has then been encrypted and sent to the receiver class. However on the way to the varifier the message has been intercepted and the plain text has been changed to "This is not a sample message". As you can see from the screen shot below because the message has been changed the hash no longer matches and the message cannot be trusted.



```
This is a sample message
sender digest : 6477f0ffeeb28d66717f744e27fe08e2b25b2b44
cipher: 747e277a0eb719f7e08181dff5ddeae40bbd4844fd34f2bbba0766f1aa8e2d282756a57fdf83d784ee965c57840a59dc8822b56c760d10a0f24507e421494366
Message sent by sender: This is a sample message
message received by verifier: This is a sample message
digest values match
verifier hash: 6477f0ffeeb28d66717f744e27fe08e2b25b2b44
sender hash  : 6477f0ffeeb28d66717f744e27fe08e2b25b2b44
```

Figure 1: Output of non intercepted message



```
sender digest : 6477f0ffeeb28d66717f744e27fe08e2b25b2b44
cipher: 7126cf6f4058c503da3874f836cf559413c704fc62be0897e2ffeeaef3a050b9f1d9262c92b0aae93352a64221065ee77f94cb76e10c75879c52ba4e6365b1b8
Message sent by sender: This is a sample message
message received by verifier: This is not a sample message
hashed values dont match this message is not trustworthy.
verifier hash: 5f35515a716b5fa74b9cde257badc4b67c21fcce
sender hash  : 6477f0ffeeb28d66717f744e27fe08e2b25b2b44
```

Figure 2: Output of intercepted message detection

### 1.3 DSA method

DSA *Appendix D* How does it work, what does it do, why does it do that and so on.

### 1.4 HMAC-SHA256 method

## 2 Diffie-Hellman with 4 parties

### 2.1 Design for the Diffie-Hellman Protocol

Following the principles of the Diffie Hellman Protocol means that in order to read the messages that are being transmitted every party needs to know the public key of all of the other members in the network in order to generate a shared secret key.

The process is largely the same when more parties are added however because more parties have been added it means that more keys need to be generated and shared. Each party starts the process by using the shared prime number ($q$) and the shared primitive root ($\alpha$ of $q$).

Each key then generates their public keys using an random integer that they have generated.

$Y_A = \alpha^{X_A}$ mod q
$Y_B = \alpha^{X_B}$ mod q
$Y_C = \alpha^{X_C}$ mod q
$Y_D = \alpha^{X_D}$ mod q

The above keys are then shared among all members of the network and then then the following calculations are performed in order to calculate the shared secret Keys

A calculates K = $(Y_{BCD})^{X_A}$ mod q
B calculates K = $(Y_{ACD})^{X_B}$ mod q
C calculates K = $(Y_{ABD})^{X_C}$ mod q
D calculates K = $(Y_{ABC})^{X_D}$ mod q

*Figure 1.* is an example of the stages that each member of the network goes through in order to finally reach a shared secret key.

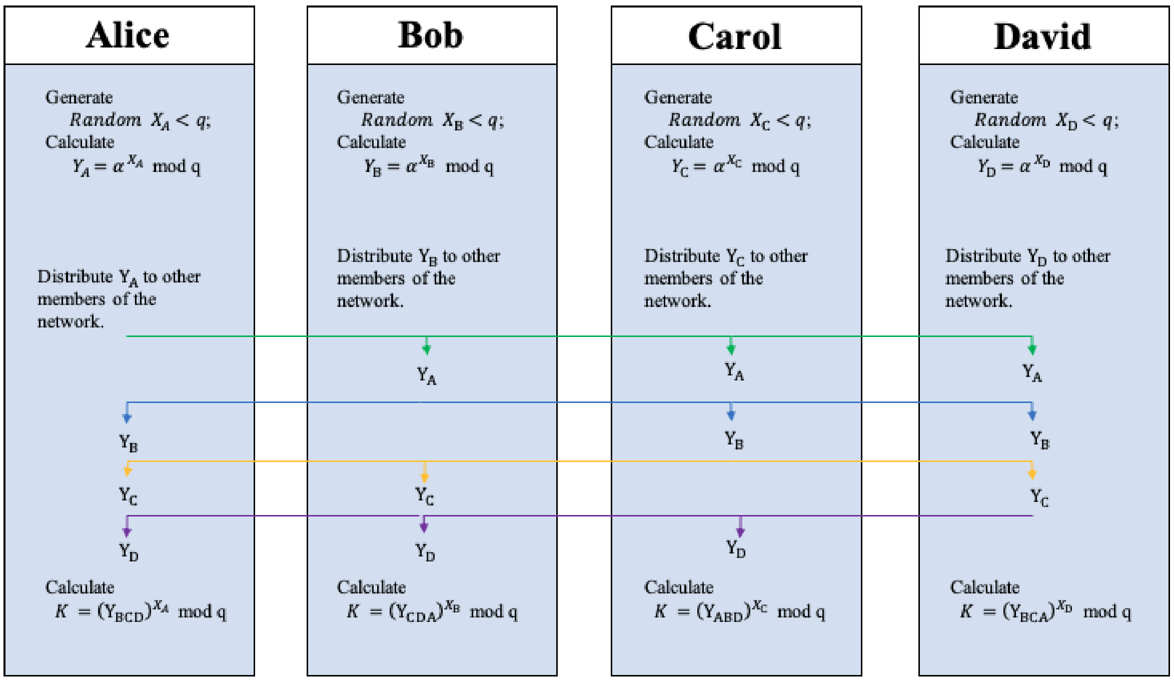

Alice
Bob
Carol
David
Generate Random $X_A < q$; Calculate $Y_A = \alpha^{X_A}$ mod q
Generate Random $X_B < q$; Calculate $Y_B = \alpha^{X_B}$ mod q
Generate Random $X_C < q$; Calculate $Y_C = \alpha^{X_C}$ mod q
Generate Random $X_D < q$; Calculate $Y_D = \alpha^{X_D}$ mod q
Distribute $Y_A$ to other members of the network.
Distribute $Y_B$ to other members of the network.
Distribute $Y_C$ to other members of the network.
Distribute $Y_D$ to other members of the network.
$Y_A$
$Y_B$
$Y_C$
$Y_D$
Calculate $K = (Y_{BCD})^{X_A}$ mod q
Calculate $K = (Y_{CDA})^{X_B}$ mod q
Calculate $K = (Y_{ABD})^{X_C}$ mod q
Calculate $K = (Y_{BCA})^{X_D}$ mod q

Figure 3: Diagram of how keys are passed between members of network.

## 2.2 Implementation of the Protocol with 4 Parties

As discussed above in section 2.1 and can be seen from the code in *Appendix D.* I have had to exchange all of the keys amongst each of the members in the network. I have done this through multiple iterations (phases) of the network in order for everyone within the network to have all of the keys needed to successfully generate a shared secret key for decoding messages that are sent. *figure 1.* shows the iteration cycle of how keys are exchanged over multiple iterations.

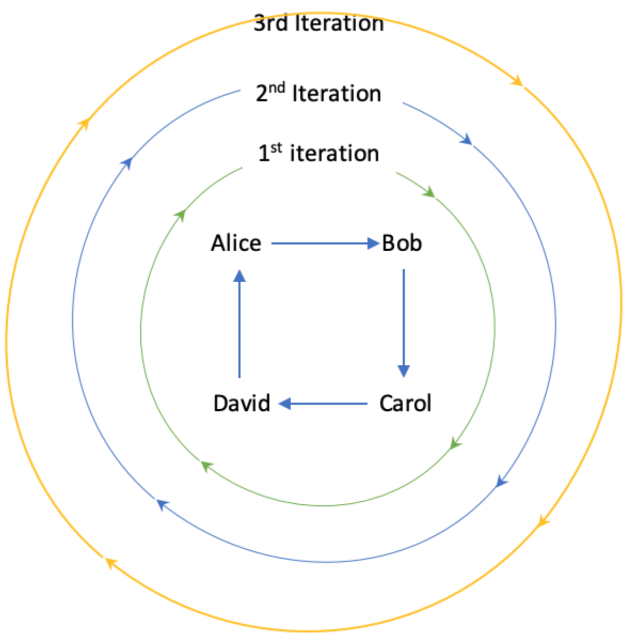


Figure 4: Diagram of how keys are passed between members of network.

*Table 1.* below details how the keys are gathered within the program. In iteration 0 the only keys that each members have are their own however as we iterate around the network the keys are gathered until every member has every other members public keys. Once every member has all of the other members public keys they are able to calculate the shared secret for the decoding of all messages. This is displayed in the code output via printing the secrets generated by each individual member and then comparing the keys. If the keys do not match then the program with throw an error however if all keys match the output should be the same as *Appendix E.*

| | Public Keys held by network members | | | |
|---|---|---|---|---|
| N | Alice | Bob | Carol | David |
| 0 | A | B | C | D |
| 1 | AD | BA | CB | DC |
| 2 | ADC | BAD | CBA | DCB |
| 3 | ADCB | BADC | CBAD | DCBA |

# Appendices

## A RSA Message Digestor

**Note:** This small digestor is used within the example for RSA Encryption with SHA-1 Hashing (*Appendix B*).

```
import java.security.MessageDigest;

/**
 *
 */
public class MessageDigestor {
    public static void main(String[] args) throws Exception {
    }

    public static byte[] messageDigest(String input) throws Exception {

        java.security.MessageDigest hash = java.security.MessageDigest.getInstance("SHA1");

        hash.update(Utils.toByteArray(input));

        return hash.digest();
    }
}
```

## B Diffie Hellman 4 Party Key Exchange

```java
/*
A Lisitsa, 2019, The code below was taken without any changes from
https://docs.oracle.com/javase/8/docs/technotes/guides/security/crypto/CryptoSpec.html#DH3Ex
*/
/*
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 * modification, are permitted provided that the following conditions
 * are met:
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 * LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING
 * NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE USE OF THIS
 * SOFTWARE, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE.
 */
import java.security.*;
import java.security.spec.*;
import javax.crypto.*;
import javax.crypto.spec.*;
import javax.crypto.interfaces.*;
/*
 * This program executes the Diffie-Hellman key agreement protocol between
 * 3 parties: Alice, Bob, and Carol using a shared 2048-bit DH parameter.
 */
public class DHKeyAgreement4 {
    private DHKeyAgreement4() {}
    public static void main(String argv[]) throws Exception {
        // Alice creates her own DH key pair with 2048-bit key size
        System.out.println("ALICE: Generate DH keypair ...");
        KeyPairGenerator aliceKpairGen = KeyPairGenerator.getInstance("DH");
        aliceKpairGen.initialize(2048);
        KeyPair aliceKpair = aliceKpairGen.generateKeyPair();

        //Do you want to see the output from the shared key generation?
        Boolean showKeys = false;

        // This DH parameters can also be constructed by creating a
        // DHParameterSpec object using agreed-upon values
        DHParameterSpec dhParamShared = ((DHPublicKey)aliceKpair.getPublic()).getParams();
        // Bob creates his own DH key pair using the same params
        System.out.println("BOB: Generate DH keypair ...");
```

```
KeyPairGenerator bobKpairGen = KeyPairGenerator.getInstance("DH");
bobKpairGen.initialize(dhParamShared);
KeyPair bobKpair = bobKpairGen.generateKeyPair();
// Carol creates her own DH key pair using the same params
System.out.println("CAROL: Generate DH keypair ...");
KeyPairGenerator carolKpairGen = KeyPairGenerator.getInstance("DH");
carolKpairGen.initialize(dhParamShared);
KeyPair carolKpair = carolKpairGen.generateKeyPair();
// David creates his own DH key pair using the same params
System.out.println("CAROL: Generate DH keypair ...");
KeyPairGenerator davidKpairGen = KeyPairGenerator.getInstance("DH");
davidKpairGen.initialize(dhParamShared);
KeyPair davidKpair = davidKpairGen.generateKeyPair();

// Alice initialize
System.out.println("ALICE: Initialize ...");
KeyAgreement aliceKeyAgree = KeyAgreement.getInstance("DH");
aliceKeyAgree.init(aliceKpair.getPrivate());
// Bob initialize
System.out.println("BOB: Initialize ...");
KeyAgreement bobKeyAgree = KeyAgreement.getInstance("DH");
bobKeyAgree.init(bobKpair.getPrivate());
// Carol initialize
System.out.println("CAROL: Initialize ...");
KeyAgreement carolKeyAgree = KeyAgreement.getInstance("DH");
carolKeyAgree.init(carolKpair.getPrivate());
//David initialize
System.out.println("DAVID: Initialize ...");
KeyAgreement davidKeyAgree = KeyAgreement.getInstance("DH");
davidKeyAgree.init(davidKpair.getPrivate());

System.out.println("Iteration 0: All parties only have their own public keys");

//gets previous persons Key
System.out.println("Iteration 1: All parties pass public key forward one.");
// Alice uses Davids's public key
Key ad = aliceKeyAgree.doPhase(davidKpair.getPublic(), false);
// Bob uses Alice's public key
Key ba = bobKeyAgree.doPhase(aliceKpair.getPublic(), false);
// Carol uses Bob's public key
Key cb = carolKeyAgree.doPhase(bobKpair.getPublic(), false);
// David uses Carol's public key
Key dc = davidKeyAgree.doPhase(carolKpair.getPublic(), false);


//gets previous previous persons key
System.out.println("Iteration 2: All parties pass public key forward two.");
// Alice uses David's result from above
Key adc = aliceKeyAgree.doPhase(dc, false);
// Bob uses Alice's result from above
Key bad = bobKeyAgree.doPhase(ad, false);
// Carol uses Bob's result from above
Key cba = carolKeyAgree.doPhase(ba, false);
//David uses Carols result from above
Key dcb = davidKeyAgree.doPhase(cb, false);


//gets previous previous previous persons Key
System.out.println("Iteration 3: All parties pass public key forward Three.");
// Alice uses David's result from above
aliceKeyAgree.doPhase(dcb, true);
// Bob uses Alice's result from above
bobKeyAgree.doPhase(adc, true);
```

```
        // Carol uses Bob's result from above
        carolKeyAgree.doPhase(bad, true);
        //David uses Carol's result from above
        davidKeyAgree.doPhase(cba, true);

        System.out.println("All parties have all public keys for everyone in the network");


        // Alice, Bob and Carol compute their secrets
        System.out.println("Calculating shared secret key.");
        byte[] aliceSharedSecret = aliceKeyAgree.generateSecret();
        byte[] bobSharedSecret = bobKeyAgree.generateSecret();
        byte[] carolSharedSecret = carolKeyAgree.generateSecret();
        byte[] davidSharedSecret = davidKeyAgree.generateSecret();

        if (showKeys) {
            System.out.println("Alice secret: " + toHexString(aliceSharedSecret));
            System.out.println("Bob secret: " + toHexString(bobSharedSecret));
            System.out.println("Carol secret: " + toHexString(carolSharedSecret));
            System.out.println("David secret: " + toHexString(davidSharedSecret));
        }

        // Compare Alice and Bobx
        if (!java.util.Arrays.equals(aliceSharedSecret, bobSharedSecret))
            throw new Exception("Alice and Bob differ");
        System.out.println("Alice and Bob are the same");
        // Compare Bob and Carol
        if (!java.util.Arrays.equals(bobSharedSecret, carolSharedSecret))
            throw new Exception("Bob and Carol differ");
        System.out.println("Bob and Carol are the same");
        if (!java.util.Arrays.equals(carolSharedSecret, davidSharedSecret))
            throw new Exception("Carol and David differ");
        System.out.println("Carol and David are the same");
    }
    /*
     * Converts a byte to hex digit and writes to the supplied buffer
     */
    private static void byte2hex(byte b, StringBuffer buf) {
        char[] hexChars = { '0', '1', '2', '3', '4', '5', '6', '7', '8',
                '9', 'A', 'B', 'C', 'D', 'E', 'F' };
        int high = ((b & 0xf0) >> 4);
        int low = (b & 0x0f);
        buf.append(hexChars[high]);
        buf.append(hexChars[low]);
    }
    /*
     * Converts a byte array to hex string
     */
    private static String toHexString(byte[] block) {
        StringBuffer buf = new StringBuffer();
        int len = block.length;
        for (int i = 0; i < len; i++) {
            byte2hex(block[i], buf);
            if (i < len-1) {
                buf.append(":");
            }
        }
        return buf.toString();
    }
}
```

## C Diffie Hellman 4 Party Output

**Note:** If you would like to print the keys out in order to visually compare them yourself you can change this with the boolean flag in the code base. Change the variable *showKeys* to false and then compile and run the program again.

These Instructions assume you are compiling from the directory that the code file is in.
**Compile:**javac ./DHKeyAgreement4.java
**Run:**java DHKeyAgreement4

**Output:**

```
ALICE: Generate DH keypair ...
BOB: Generate DH keypair ...
CAROL: Generate DH keypair ...
CAROL: Generate DH keypair ...
ALICE: Initialize ...
BOB: Initialize ...
CAROL: Initialize ...
DAVID: Initialize ...
Iteration 0: All parties only have their own public keys
Iteration 1: All parties pass public key forward one.
Iteration 2: All parties pass public key forward two.
Iteration 3: All parties pass public key forward Three.
All parties have all public keys for everyone in the network
Calculating shared secret key.
Alice and Bob are the same
Bob and Carol are the same
Carol and David are the same
```