95-702 Distributed Systems

Project 2

Assigned: Sunday, February 1, 2015

Due: Midnight, Sunday, February 15, 11:59pm

Principles

In this project, we attempt to illustrate several non-functional characteristics of distributed systems. One such characteristic is reliability. UDP is considered an unreliable protocol since it does nothing to ensure that packets arrive at their destination. In Task 1, we build a small client and server that use UDP to communicate. In Task 2, we add a measure of reliability to UDP with positive acknowledgements and retransmission.

Interoperability and performance (speed) are also important characteristics of distributed systems. In Task 3, we write a client and a server that exchange binary data. It is essential that both the client and the server know how to properly interpret the binary data sent and received. The binary transmission is fast – there is no need to convert the data coming off the network (or going to the network) into any special format.

Along the way, we introduce the proxy design pattern. This is a common pattern in distributed systems. The proxy design pattern is one example of the very sound engineering principle that we should strive to separate concerns. We see the same proxy pattern used in web services, RPC, and RMI. These topics will be visited carefully later in the course.

In Task 4, we build a secure system using symmetric key cryptography. The encryption occurs just above the TCP layer and is provide by the Tiny Encryption Algorithm (TEA). User authentication with ID's and passwords is done in the application layer. This is a common theme in modern systems. User names and passwords are passed over an encrypted, but otherwise insecure, channel. Thus, in Task 4, our main concern is with security – another important characteristic of many distributed systems. In Task 4, there is an opportunity for bonus points. So, in this project, you may score above 100%.

For each task below, you must submit screenshots that demonstrate your programs running. These screenshots will aid the grader in evaluating your project.

Review

In Project 1 we worked with J2EE servlets and Java Server Pages using the Glassfish application server.

In this project we will be working at a lower level. That is, we will not have the Glassfish runtime environment to rely on. You may, however, continue to use Netbeans for all of this work. In this project, we will be programming with UDP and TCP sockets.

Discussion of UDP and TCP

In this project you will work with both UDP and TCP over IP. UDP is a simpler protocol than TCP and therefore usually requires more work from the application programmer. TCP presents the application programmer with a stream abstraction and is busier behind the scenes. TCP, unlike UDP, tries its best to make sure packets are delivered to the recipient. The underlying network we are using may, on occasion, drop packets. So, how can TCP provide for reliable delivery of packets? TCP uses the fundamental principal of "positive acknowledgement with retransmission".

A simplified example of "positive acknowledgement with retransmission" looks like the following. In this scenario, no packets are lost. These notes are adapted from "Internetworking with TCP/IP, Volume I: Principles, Protocols and Architecture" by Douglas E. Comer

Cool example: Positive acknowledgement with retransmission

```
Sender                          Service
=====================================================

  Send packet 1
  Start timer
                                  Receive packet 1
                                  Send ACK for packet 1
  Receive ACK 1
  Cancel timer

  Send packet 2
  Start timer
                                  Receive packet 2
                                  Send ACK for packet 2
  Receive ACK 2
  Cancel timer
```

Here is an example where the first packet is lost.

```
Sender                          Service
=====================================================

  Send packet 1
  Start timer
                  Packet lost


  Time expires
  Send packet 1
  Start timer
                                  Receive packet 1
                                  Send ACK for packet 1

  Receive ACK 1
  Cancel timer

  Send packet 2
  Start timer
                                  Receive packet 2
                                  Send ACK for packet 2
  Receive ACK 2
  Cancel timer
```

Here is an example where the first ACK is lost.

```
Sender                          Service
=====================================================

  Send packet 1
  Start timer
                                  Receive packet 1
                                  Send ACK 1
                  ACK 1 lost

  Time expires
  Send packet 1
  Start timer
                                  Receive packet 1 a second time
                                  Send ACK for packet 1

  Receive ACK 1
  Cancel timer

  Send packet 2
  Start timer
                                  Receive packet 2
                                  Send ACK for packet 2
  Receive ACK 2
  Cancel timer
```

The acknowledgement may be replaced with the result of the service. Here is another example.

```
Sender                          Service
=====================================================

  Send packet 1
  Start timer
                                Receive packet 1
                                Send response
                 Response
                 Lost

  Time expires
  Send packet 1
  Start timer
                                Receive packet 1 a second time
                                Send response again

  Receive response
  Cancel timer

  Send packet 2
  Start timer
                                Receive packet 2
                                Send response for packet 2
  Receive response
  Cancel timer
```

Task 1A

In Figures 4.3 and 4.4 of the Coulouris text, two short programs are presented. UDPClient.java and UDPServer.java communicate by sending and receiving UDP packets. The code for these programs can be found at:

http://www.cdk5.net/wp/extra-material/source-code-for-programs-in-the-book

Make modifications to UDPClient.java and UDPServer.java so that the client may ask the server to perform simple integer arithmetic. You need to implement addition, subtraction, multiplication, exponentiation and division of integers. You may assume that you have a well-behaved user and all input is correct. You may also assume that the user uses spaces to separate arguments. For the mathematical operators, use '+', ' –','/', and '^' (for exponentiation). Use the letter 'X' (not '*') for multiplication. Each expression entered by the user will have two operands and a single operator and will be represented in postfix (reverse Polish) notation.

The server will be executed first and will announce each visit. An example execution will look like the following:

```
java UDPServer
Received request for 2 3 ^
Received request for 2 3 +
:
```

The execution of the client program will prompt the user for input and will look like the following two examples:

```
java UDPClient
Enter simple postfix expression to be computed by the server:
2 3 ^
2 3 ^ = 8

java UDPClient
Enter simple postfix expression to be computed by the server:
2 3 +
2 3 + = 5
```

Note that the server and not the client actually performs the arithmetic operation. Note too that only one UDP message is sent to the server. There is no good reason to send three separate DatagramPackets.

UDPClientArithmetic.java and UDPServerArithmetic.java will be placed in a project called Project2Task1 and submitted to Blackboard.

Task 1B

Using the same UDP server that you wrote for Task 1A, write a new UDP client named UDPClientWithProxy.java that has a main routine that prompts the user for an integer k >= 1 and then computes and displays the value of the sum from 1 to k. That is, if the user enters 100, your program will compute the sum 1+2+...+100 and will display the result 5050. The main routine of the client must be very clean and contain no socket level programming. All of the socket work will be done within a single method with the following signature:

```
//precondition: x and y are two integers
// postcondition: the value x + y is returned
public static int add(int x,int y);
```

The add method will send a message to the server and the server will perform the addition. There should be no need to change the server from the one you wrote in Task 1A.

Your main method may test if k == 1 and then simply display the value 1. If, however, the value for k is greater than 1, you will need to make calls on add(). It is required that your client program perform no direct additions. Instead, add() sends messages to the server asking it to provide the sum of two integers.

This is an example of the proxy design. The add() method is simply being used as a proxy for the server and the server is where the addition is actually being carried out.

This is a design we will visit several times in the course. It's a simple example of the principle of separation of concerns. The main routine programmer need not be (should not be) aware of how the add() method is working.

You may assume that your user is friendly and will enter a reasonable integer k >= 1. No data validation or overflow handling is required.

Here is a sample execution:

```
java UDPClientWithProxy
Enter an integer >= 1
3
1 + 2 + 3 = 6
```

UDPClientWithProxy.java will be placed in the same project (Project2Task1) as Task 1A.

Task 2

Build a new project called Project2Task2. Modify the UDPServer.java code and create a new Java class called UDPServerThatIgnoresYou.java. Write the new server so that it randomly ignores 80% of requests – a very unreliable server. In other words, the new UDPServerThatIgnoresYou will contain code close to this:

```
// rnd is an object of the Random class
aSocket.receive(request);
if(rnd.nextInt(10) < 8) {
      System.out.println("Got request " +
          new String(request.getData())+
            " but ignoring it.");
      continue;
}
else {
      System.out.println("Got request" +
          new String(request.getData()));
      System.out.println("And making a reply");
}
```

Create a new client called UDPClientWithReliability.java. This new client is a modification of UDPClientWithProxy. After a request, it waits only 2 seconds for a reply. If the reply does not arrive after two seconds, the client tries again. Unlike many such systems, this one never gives up. The client side UDP receive logic will look something like this.

```
aSocket.setSoTimeout(2000);
aSocket.receive(reply);
```

See the above discussion on "positive acknowledgement with retransmission".

UDPClientWithReliability.java will have a main routine that prompts the user for k >= 1 and then computes and displays the sum from 1 to k. The main routine of the client must be very clean and contain no socket level programming. All of the socket work (and retry code) will be done by a single method with the following signature:

```
//precondition: x and y are two integers
// postcondition: the value x + y is returned
public static int add(int x, int y);
```

All files for this Task should be in a project named Project2Task2. You only need to change the server and implement the add() method to perform retries. This is an example of adding reliability to UDP.

Task 3

Build a new project called Project2Task3. Write a UDP server called UDPServerWithDoubleArithmetic.java that receives two double operands and an operator from a UDP client and returns the double result after applying the operator ('+', 'X', '-', or '/') to the two double operands.

Create a new client called UDPClientWithDoubleArithmetic.java. This new client will use the server and will compute the sum 1.25 + 2.25 + 3.25 +...+100.25. As we did above, the main routine of the client should be free of any networking. For simplicity, this program does not prompt the user. The main routine simply makes calls on a proxy to compute the sum.

The point of this task is to work with marshaling and un-marshalling of parameters other than simple integers or character text. In this task, you will be reading and writing binary data rather than string data. In other words, we will not be taking doubles and converting them to strings before writing bytes to the wire. Instead, we will be writing the binary data (doubles) to the wire directly. The binary data is read by the server with no conversion from a string representation. In my solution, I made good use of the following Java methods:

```
double Double.longBitsToDouble(long);
long Double.doubleToLongBits(double);
```

In addition, I made good use of the following method (from StackOverflow):

```
public static long byteArrayToLong(byte bytes[]) {
```

```
        long v = 0;
        for (int i = 0; i < bytes.length; i++)
        {     // bytes[i] will be promoted to a long with the byte's leftmost
              // bit replicated. We need to clear that with 0xff.
              v = (v << 8) + (bytes[i] & 0xff);
        }
        return v;
    }
```

You may use byteArrayToLong() in your solution, but please take some time and study how it works. You will be required to understand this kind of code (bit manipulation using & and <<) on exams. 0xff is a hexadecimal value that represents 11111111 in binary. The byte will be converted to long. The mask is used to remove any replicated 1 bits.

As a thinking exercise, how would this system perform when compared with one that converted doubles to strings before transmission? Which would be faster? Which would be more interoperable?

Task 4

This project will be named Project2Task4.

In this task we will make use of the Tiny Encryption Algorithm (TEA). You are not required to understand the underlying mechanics of TEA. You will need to be able to use it in your code. Later in the course, we will discuss TEA and describe it as one of many symmetric key encryption schemes. TEA is well known because of its small size and speed.

In Figure 4.5 and 4.6 of the Coulouris text, two short programs are presented: TCPClient and TCPServer. You can also find these programs at:

http://www.cdk5.net/wp/extra-material/source-code-for-programs-in-the-book

The TCPClient program takes two string arguments: the first is a message to pass and the second is an IP address of the server (e.g. localhost). The server will echo back the message to the client. Before running this example, look closely at how the command line argument list is used. You will need to include localhost on the command line. In Netbeans, command line arguments can be set by choosing Run/Set Project Configuration/Customize.

Make modifications to the TCPClient and TCPServer programs so that spies in the field are able to securely transmit their current location (longitude and latitude) to Intelligence Headquarters. Intelligence Headquarters is run by Sean Beggs. There are three spies and one spy commander as listed here:

Unique User-id	password	title	location
jamesb	james	spy	long, lat, alt
joem	joe	spy	long, lat, alt
mikem	mike	spy	long, lat, alt
seanb	sean	Spy Commander	Base Location

The spies are required to inform Sean of their locations as they move about the world (on super secret missions). Sean uses Google Earth to view the locations of his spies. The spies communicate over a channel encrypted using TEA. TEA is a symmetric key encryption algorithm and so Sean has provided his spies with the symmetric key before they left Hamburg Hall on their missions. Of course, Sean's software knows the ID and password of each spy. So, while TEA is used for encryption, authentication is provided by the user name and password.

Name these two new programs TCPSpyUsingTEAandPasswords.java and TCPSpyCommanderUsingTEAandPasswords.java. The first is a TCP client used by each spy in the field. The second is a TCP server used by Spy Commander Beggs.

Here is an example execution of the server on Sean's machine.

```
java  TCPSpyCommanderUsingTEAandPasswords
Enter symmetric key for TEA (taking first sixteen bytes):
thisissecretsodon'ttellanyone
Waiting for spies to visit...
Got visit 1 from Mike
Got visit 2 from Joe
Got visit 3 from James
Got visit 4 illegal symmetric key used.
Got visit 5 from James. Illegal Password attempt.
```

Here is an example execution of the client on Mike's machine.

```
java  TCPSpyUsingTEAandPasswords
Enter symmetric key for TEA (taking first sixteen bytes):
thisissecretsodon'ttellanyone
Enter your ID: mikem
Enter your Password: mike
Enter your location: -79.956264,40.441068,0.00000
Thank you. Your location was securely transmitted to Intelligence Headquarters.
```

Here is an example execution of the client on Joe's machine.

java TCPSpyUsingTEAandPasswords

Enter symmetric key for TEA (taking first sixteen bytes):

thisissecretsodon'ttellanyone

Enter your ID: joem

Enter your Password: joe

Enter your location: -79.945389,40.444216,0.00000

Thank you. Your location was securely transmitted to Intelligence Headquarters.

Here is an example execution of the client on James Bond's machine.

java TCPSpyUsingTEAandPasswords

Enter symmetric key for TEA (taking first sixteen bytes):

thisissecretsodon'ttellanyone

Enter your ID: jamesb

Enter your Password: james

Enter your location: -79.940450,40.437394,0.00000

Thank you. Your location was securely transmitted to Intelligence Headquarters.

Here is an example execution of the client by Mallory. (She broke into Joe's office and ran his copy of the client.)

java TCPSpyUsingTEAandPasswords

Enter symmetric key for TEA (taking first sixteen bytes):

IBetTheyUseThisKeyAsTheSecret

Enter your ID: joem

Enter your Password: sesame

Enter your location: -79.940450,40.437394,0.00000

Some exception is thrown on client (The server ignores this request after detecting the use of a bad symmetric key and the server notifies Sean.)

Here is an example execution of the client by James Bond (who forgot his password).

java TCPSpyUsingTEAandPasswords

Enter symmetric key for TEA (taking first sixteen bytes):

thisissecretsodon'ttellanyone

Enter your ID: jamesb

Enter your Password: jimmy

Enter your location: -79.940450,40.437394,0.00000

Not a valid user-id or password.

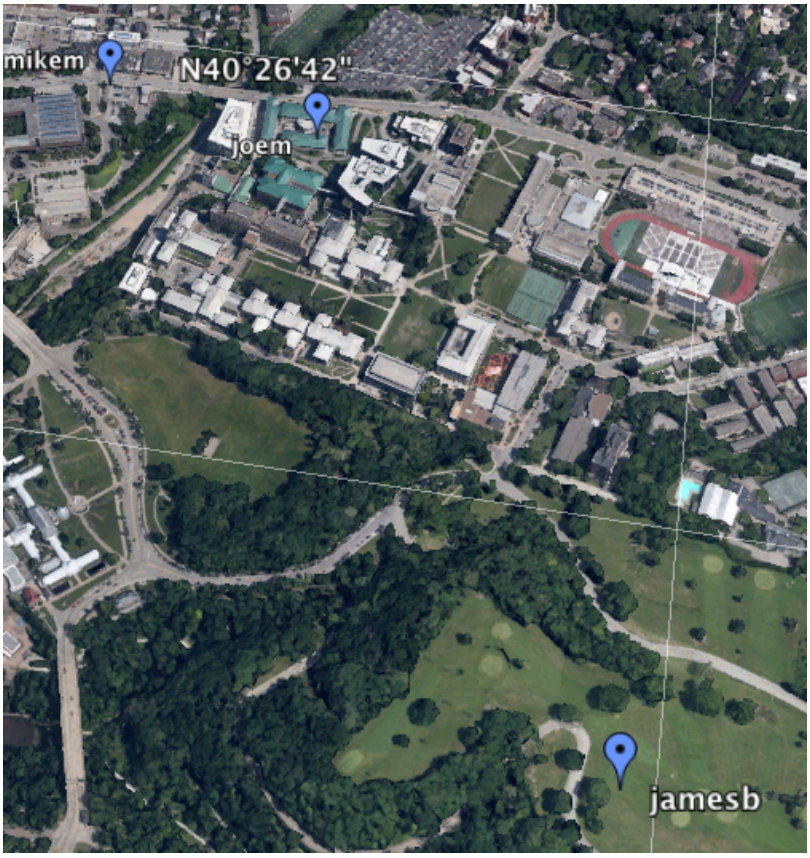
After each visit by an authenticated spy, the server writes a file called SecretAgents.kml to Sean's desktop. Here is a copy of a typical KML file that may be loaded into Google Earth.

SecretAgents.kml

```
<?xml version="1.0" encoding="UTF-8" ?>
<kml xmlns="http://earth.google.com/kml/2.2"
><Document>
<Style id="style1">
<IconStyle>
<Icon>
<href>http://maps.gstatic.com/intl/en_ALL/mapfiles/ms/micons/blue-dot.png</href>
</Icon>
</IconStyle>
</Style><Placemark>
<name>jamesb</name>
<description>Spy</description>
<styleUrl>#style1</styleUrl>
<Point>
<coordinates>-79.940450,40.437394,0.0000</coordinates>
</Point>
</Placemark>
<Placemark>
<name>joem</name>
<description>Spy</description>
<styleUrl>#style1</styleUrl>
<Point>
<coordinates>-79.945389,40.444216,0.00000</coordinates>
</Point>
</Placemark>
<Placemark>
```

<name>mikem</name>
<description>Spy</description>
<styleUrl>#style1 </styleUrl>
<Point>
<coordinates>-79.948460,40.444501,0.00000</coordinates>
</Point>
</Placemark>
</Document>
</kml>

When loaded, SecretAgents.kml looks like this in Google Earth.



Note that Joe is at work in Hamburg Hall, Mike is hanging out at Starbucks and James Bond is golfing.

You are required to rewrite the entire file (SecretAgents.kml) after each visit from a spy. The file always contains data on all three spies. This means that you need to maintain the state on the server for each spy. This would include location data, user ID, password, and a title for display on Google Earth (see the Description element in the KML file).

If a visitor (spy) does not have the correct ID or password, no change will be made to the SecretAgents.kml file. The server will send a message to the client saying illegal ID or password.

If a visitor (evil spy) enters an illegal symmetric key, the server will detect that and close the socket. How the client behaves at this point is of no real concern. The server should not deal at all with anyone with an illegal symmetric key. One way you might detect the use of this attack is to check if the decrypted data is properly formatted and standard ASCII. It would be a mistake to have the symmetric key stored in the Java code on the client. That is, you can't simply test the user entered symmetric key against a key stored in the client side code.

You may assume that the location data is accurate and well formed. That is, you do not have to validate the longitude, latitude, or altitude. The spies are always careful to enter these data correctly.

Initially, before any spy has communicated with the server using TEA over TCP, all of the spies have their initial state stored in memory objects on the server. How you do this is of your own design. Each spy is initially located in Hamburg Hall (see Joe's coordinates in the KML file).

As soon as the first spy visits using TEA and TCP, the SecretAgents.kml file is re-written with that spy's new location. The other values (for the other spies still located in Hamburg Hall) are also re-written to the file. Thus, the file should always have data for all three spies (in Hamburg Hall or not). The KML file only needs to be written. It is read only by Google Earth. The KML file may be written as a single Java String. There is no need for an XML parser, we are only writing an XML string to a file.

From the Spy Commanders point of view, he runs the server and leaves it running all day and all night. On occasion, perhaps every few hours, he loads the SecretAgents.kml file into Google Earth to see where his spies are located. We are not writing an automatic refresh into Google Earth (maybe next term).

See Wikipedia and see the course schedule for a copy of TEA.java (which you may use.) Name this project Project2Task4. It will contain the files:

TCPSpyUsingTEAandPasswords.java and

TCPSpyCommanderUsingTEAandPasswords.java

TEA.java. Other files may be included as needed.

In my solution, since I am reading and writing streams of bytes, I did not use writeUTF() and readUTF(). Instead, I used these methods in DataInputStream and DataOutputStream:

public final int read(byte[] b)

public void write(byte[] b)

The return value of the read method came in very handy.

Note: You may not assume that the symmetric key entered (by a spy) is valid. That is, you should detect when an invalid key is being used. You may assume that the key that the Spy Commander enters is correct and has been secretly provided to and memorized by each spy. Hint: Postpone this concern until you have the happy case working.

Five Points Bonus: Rather than storing the user id and password in the server side code (insecure if Eve steals a copy of the server source code), store the user id, some cryptographic salt and a hash of the salt plus the password in the code. When authenticating, use the user id to find the salt and hash of salt plus password pair. Hash the salt with the user provided password and check for a match with the stored hash of salt plus password pair. You may use SHA-1 or MD5 as you did in the first project.

Final note. It is a bad idea to write your own cryptography software – unless you are an expert with years of experience. We do this exercise only to understand and explore some major issues in cryptography.

Project 2 Summary

Be sure to review the grading rubric on the schedule. We will use that rubric in evaluating this project. Documentation is always required.

There will be 4 projects in Netbeans.

- Project2Task1
- Project2Task2
- Project2Task3
- Project2Task4

You should also have four screen shot folders:

- Project2Task1ScreenShots

- Project2Task2ScreenShots
- Project2Task3ScreenShots
- Project2Task4ScreenShots

Copy all of your Netbeans project folders and screenshot folders into a folder named with your id.

Zip that folder and submit it to Blackboard.

The submission should be a single zip file.