COMPSCI 453: Computer Networks

Professor Jim Kurose

Fall 2020

Programming Assignment 2: A Reliable data transfer protocol V0.95[1]

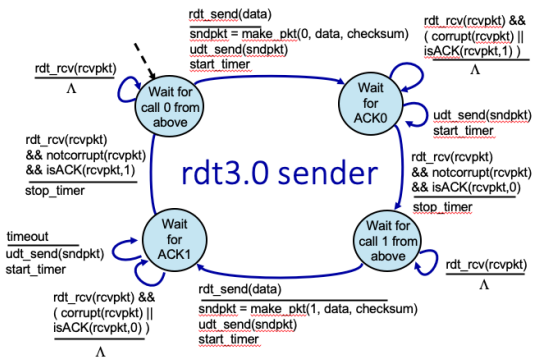
Assigned 10/1/20

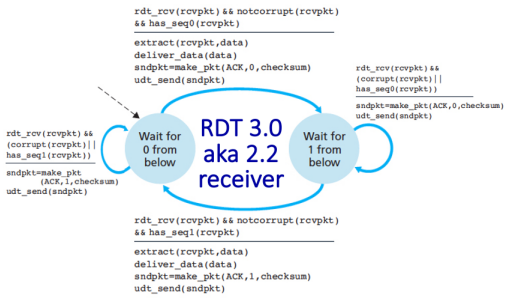
Due: 10/19/20 (Note: 10/19 is a Monday. You have more time than needed to complete this because of intervening midterm exam)

1. Overview and Introduction

In this second programming assignment, you'll be writing the sending and receiving transport-level code for implementing a simple reliable data transfer protocol, specifically using an implementation of the rdt 3.0 protocol that we studied in class. It will operate over a channel that can corrupt, lose, or delay (but not reorder) messages. This should be *fun* since your implementation will differ very little from what would be required in a real-world situation.

The sending and receiving sides FSMs for the rdt 3.0 protocol are shown in Figure 1. The most important difference between rdt 3.0 and what you'll implement is that your sender will not be called via an `rdt_send(data)` from above, nor will your receiver deliver data to above via `udt_send(data)`. Instead, as discussed below, your sender will reliably deliver a file from sender to receiver. And, of course, your sender and receiver will be communicating over sockets, over a "live" Internet.





[1] Any significant updates to this assignment will be given a new version number with changes notes here and highlighted in the assignment document.

Figure 1: rdt 3.0 sender and receiver. The logic and data-transfer protocol behavior will be the same as show here, but the implementation details (e.g., socket calls) will differ from the abstract functions shown here.

In this assignment you will program a sender and receiver that will reliably transfer the first 200 characters of text of the Declaration of Independence (the text is here: http://gaia.cs.umass.edu/cs453_fall_2020/files/declaration.txt, download this file to the machine where you sender is executing) from sender to receiver, using the rdt 3.0 protocol. The sender and receiver will communicate over the network environment described below in Section 3.

2. rdt 3.0 protocol details

Because your sender and receiver will operate over a channel that can corrupt, lose, or delay (but not reorder) messages, you'll want to use checksums, sequence and acknowledgement numbers (one-bit numbers will suffice), and timeout and retransmit mechanisms – all part of the rdt 3.0 protocol. Because your sender will need to interact with your receiver, as well as my receiver running on gaia.cs.umass.edu and receivers written by other students, and your receiver will need to work the senders of other students (as described below), we'll need to be *incredibly* precise about rdt 3.0 protocol packet formats.

To make things as easy as possible for you, a packet should be encoded as a single *string*. Thus, for example, rather than sending the binary encoding of an integer value such as 1 as a field in the packet, you would send the substring '1' as a field in the packet.[2] The format of a packet sent between sender and receiver should be as follows:

```
<integer sequence number> <space> <integer ACK number> <space>
<20 bytes of characters – payload> <space> <integer checksum
represented as characters>
```

There <integer sequence number is a '0' or '1' character. So the string

```
'1 0 That was the time it  <checksum represented as characters>'
```

would be a sender-to-receiver packet with a sequence number 1, ACK number 0 (note that the sender-to-receiver ACK value is never used by the receiver), a 20-byte payload of 'That was the time it' and the string representation of the computed checksum computed over the entire prefix up to the start of the checksum, i.e., '1 0 That was the time it'. For a receiver-to-sender ACK, the entire string except for the ACK value itself and the checksum should be blank, e.g.,

```
'  1                          <checksum represented as characters>'
```

[2] This will allow us to not have to worry about Big-endian versus Little-endian storage of integers on different types of computers, and the consequent need to carefully translate between network-byte-order and host-byte-order when sending integer field values. See https://pythontic.com/modules/socket/byteordering-coversion-functions for a discussion of what you would have to do in Python if actual integer values were sent. Note that we've already seen that application-layer protocols such as HTTP send the string representation of a number, rather than the binary representation of that number.

- **Checksumming.** To compute the checksum, add together the ASCII values of all of the bytes in the string as if they were integers, and include the string representation of that sum as the checksum at the end of the packet string. Note that the checksum is NOT computed over the checksum itself, but should be computed over all other butes in the string, including the sequence number, ACK number, blank spaces, and 20-character payload. Our TA's have written checksumming routines that you can use in Python and Java (thank you Ahmad and Nikko!); you can pick them up at http://gaia.cs.umass.edu/cs453_fall_2020/files/checksum.py (Python) or at http://gaia.cs.umass.edu/cs453_fall_2020/files/checksum.java (Java). One reason it's important to make sure everyone get the checksum done correctly is that senders and receivers from different students will need to interoperate, and therefore will need to compute the checksum *exactly* the same way.
- **Timeout/retransmit.** You learned about how to use Python timers in the first programming assignment, so this will hopefully not be too much of a heavy lift. You will set your timeout value as discussed below. There may be premature timeouts because of packets being delayed within the network environment discussed in section 3, but your protocol (rdt. 3.0) is (as we've learned) able to handle this scenario

3. The network environment

Your sender and receiver will communicate with each other through an intermediary server running on gaia.cs.umass.edu, as shown below in Figure 2, that will function as an unreliable channel connecting your sender and receiver. Your sender and receiver will each send messages (see section 2 above) to the server, and the server will relay (after possibly corrupting, losing or delaying but not reordering) the message to your other side.

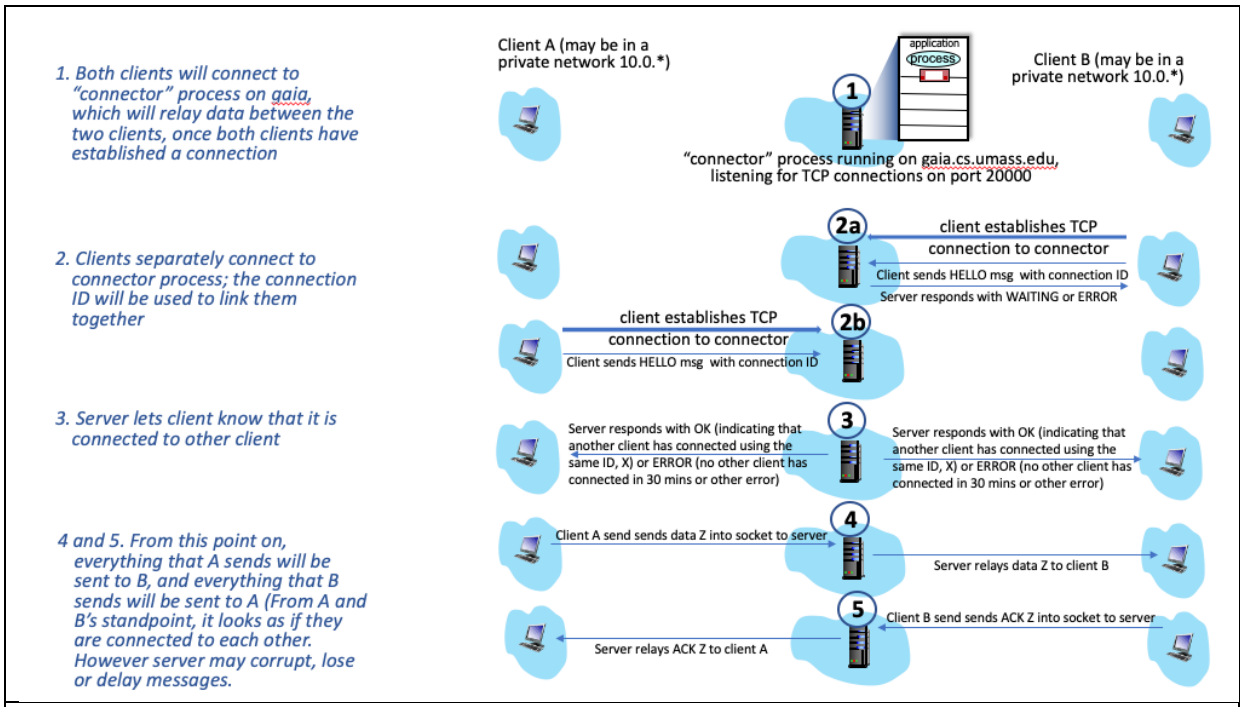


Figure 2: A server at gaia.cs.umass.edu acting as a relay (possibly unreliable) between two clients

Before your sender and receiver can communicate with each other they must first each establish a connection with a gaia.cs.umass.edu server as follows. Your sender and receiver (which are separate programs) should each:

- Create a TCP socket, as a client, and connect() it to port 20000 at gaia.cs.umass.edu.
- The sender side of your protocol would then send a string of the following form on this socket:

  "HELLO S <loss_rate> <corrupt_rate> <max_delay> <ID>"

  while the receiver side of your protocol would send a string of the form:

  "HELLO R <loss_rate> <corrupt_rate> <max_delay> <ID>"

  to the server where:
  - <loss_rate> <corrupt_rate> are float values in the range [0.0, 1.0]. <loss rate> and <corrupt rate> are the probabilities that a message will be lost or corrupted, respectively. Set these values initially to 0.0 when you're starting to work on this project.
  - <max_delay> is an int value ranging [0, 5] representing maximum delay for your packet at server. Set this initially to 0 also.
  - <ID> is a string with four digits specifying the connection ID of the client.

    An example HELLO message from a sender is "HELLO S 0.0 0.0 0 1234". Your sender and receiver should specify the same connection ID (this is how the server will know to relay messages between these two TCP clients). Try to pick a "random" ID since if that number is currently in use by someone else, you'll get an error message (see below).

  Your sender and receiver sides can set the parameter values differently, meaning that the sender-to-receiver receiver-to-sender directions of the channel may have different characteristics. Your sender and receiver must make a request with the same connection ID within 60 seconds of each other; otherwise you'll get an `ERROR` message (see below).
- The gaia.cs.umass.edu server will respond to your client (your client must do a read from the socket to get this response) with a string with one of several different messages:
  - An "`OK`" message (containing the string 'OK') received by a client means that it is connected to another client that requested that same ID. This is the message you are hoping for! After this point, *everything your sender or receiver sends – using the same socket that was used to communicate with the gaia server – will be relayed to the other side by the gaia.cs.umass.edu server.*
  - A "`WAITING` message" (containing the string 'WAITING') means that the server is waiting for another client to connect within the next 60 seconds. After receiving a `WAITING` message, your client should then again read form the socket, and will receive, either an `OK` or an `ERROR` message.
  - An "`ERROR`" message (containing the string 'ERROR') will include an error reason statement as part of the string beginning with 'ERROR' that will

indicate what went wrong. Possible errors are an "Incorrect Parameter Values" (indicating one or more of the parameters specified in your HELLO message are invalid), "CONNECTION ID IN USE" (indicating that another sender/receiver pair are already communicating using the Connection ID you specified) and "NO MATCHING CONNECTION REQUEST" meaning that no other client has made a request in the last 60 seconds for the same Connection ID, so your client could not be connected to another client.

When your sender and receiver are done with their task of reliably transferring a file, they must gracefully close the socket connection to the gaia server. If your sender closes the TCP connection to the server when it's done, the gaia server will then close its two sockets that are used to communicate to your sender and receiver, and this, in turn, will cause your receiver to get a socket closed error message (check!) on a socket read, meaning that your receiver will know it's done and can gracefully close its socket.

If you want to check out what's happening at the gaia.cs.umass.edu server at port 80, you can checkout its logfile of that requests it has received by checking out the following webpage http://gaia.cs.umass.edu/cs453_fall_2020/files/PA2_log.php [Note: this will be implemented as of 10/3/20].

Whew! As you can see, even before implementing your sender/receiver reliable data transfer protocol, you've implemented the client side of a channel establishment protocol. ☺ Congratulations!

4. The Assignment

Write a reliable data transfer protocol rdt 3.0 to transfer the first 200 bytes (characters) of the "declaration of independence" file from sender to receiver. (Reminder: the text is here: http://gaia.cs.umass.edu/cs453_fall_2020/files/declaration.txt, download this file to the machine where you sender is executing)

Your sender should be named "sender.py" and invoked as follows from the command line

```
python3 sender.py <connection_id> <loss_rate> <corrupt_rate>
<max_delay> <transmission_timeout>
```

Your receiver should be named "receiver.py" and invoked as follows from the command line

```
python3 receiver.py <connection_id> <loss_rate> <corrupt_rate>
<max_delay>
```

When starting up, your client and server should then print out your name, the date and time. When the sender or server has set up the socket to the gaia server and received an OK message from the gaia server, your client and server should print out date and time and a string indicating that the channel has been established.

After transferring the file, and before exiting, your client and server should then print out your name, the date and time, followed by the checksum of the 200 bytes of data from the "declaration of independence file" that were sent (sender-side) or received (receiver-size), and statistics of the file transfer: the total number of packets sent, the total number of packets received, the number of times a corrupted message was received, and the number of timeouts (a sender-side0only statistic) that occurred. So you'll need to gather these statistics as your rdt 3.0 protocol operates.

5. Getting started

This isn't a project you'll be able to do in an evening, as there are many pieces you'll need to get right: the channel establishment, your use of sequence numbers, ACKs, and timers, and the overall logic and correct operation of your rdt protocol. I'd *strongly* recommend you proceed in steps:

1. Write code for two clients that establish a connection to each other through the gaia.cs.umass.edu server, as discussed in section 3. [The gaia.cs.umass.edu server will be operational Saturday evening 10/3/20. So for now, I'd recommend you work on step 2]. Then abandon this code but keep it handy, as you can cut and paste it into step 3. Note you can do step 2 below before step 1 if you want to.
2. Write your rdt sender and receiver code using sequence numbers, ACK, timers using the message format described in Section 2, and implement the assignment in Section 4. Program your sender and receiver to communicate with each other via TCP or UDP sockets, using the loopback interface 127.0.0.1. That is, they'll connect directly to each other in this step, rather than via the gaia server. With this configuration, it will be unlikely that there are errors or significant delays between your sender and receiver. This will allow you to get an interoperable sender and receiver up and running in this benign environment first.
3. Integrate your code from steps 1 and 2 into a sender and receiver that connect to the gaia server *and* transfer the file over a reliable channel that you configure (via the initial HELLO message discussed in Section 3) with 0.0 loss, 0.0 corruption and 0 delay. When you've gotten this far, you're getting very close to done!
4. Now test and debug your code by selectively turning on more and more channel impairments.
    a. Initially set channel loss and delay at zero, but channel corruption to a non-zero value, first in just the sender-to-receiver direction, and then in both directions. Does your protocol handle corrupted messages correctly, with no loss or delay?
    b. Now turn off channel corruption, but turn on channel loss, first in just the sender-to-receiver direction, and then in both directions. Does your protocol handle lost messages correctly, with no corruption or delay?
    c. Now turn on both channel loss and corruption. Does your protocol handle the occurrences of both corruption and loss in the same execution run?
    d. Now turn off corruption and loss, but use a high channel delay and a small timeout. Does your protocol handle premature timeouts correctly (e.g., does it transfer the file with no missing or out-of-order data).
5. If you've got 4a – 4d all working correctly, I'll give you 10-1 odds that when you turn channel corruption, loss, and delay on at the same time, that it will all work without

errors. I'll give you 100-1 odds that if you programmed this all at once and turned everything on and started debugging that it would have taken at least 5 times as long to test and debug than having proceeded through steps 4a – 4d one at a time!

6. Connecting your sender and receiver to a receiver and a sender written by someone else.

One of the great things about well-specified protocols is that two people can independently write the two different "sides" of a protocol and those implementations should interoperate. That will be the case here as well.

First, you can test your sender by connecting to a receiver on gaia.cs.umass.edu that has implemented the receiver-side of the assignment and is wait for you using connection ID 9999 (So please do not use this connection ID unless you are testing your sender with this receiver on gaia.cs.umass.edu!). You can configure your channel (loss and corruption probabilities, delay) to this receiver however you'd like. The channel from the receiver to your server will *not* corrupt, lose or delay messages. [This client will be operational on the evening of 10/3/20].

Secondly, you should find another student in the class who is willing to run their receiver to operate with your sender, and willing to their sender with your receiver. So actually, you're both doing this for each other. You can find another student to connect with by writing and replying to Posts on the Piazza find-a-co-tester thread. [This co-tester will be created 10/4/20]. Once you find someone willing to co-test with, please take your arrangements to co-test offline (i.e., not on Piazza broadcast) to email, texting or whatever communication mechanism you want. All students are required to demonstrate interoperability of their sender and receiver with another student (see section 7 below), so everyone will need to find at least one partner. Andif you're co-testing with them, then they're co-testing with you. It'd be great if you'd co-test with multiple other students – you can help each other out, and get to meet other students in the class!

If you'd prefer not to advertise or respond about co-testing via Piazza, just email the instructor (kurose@cs.umass.edu), and I'll arrange something. But I encourage you to interoperate with other students in the class – it'll give you a chance to meet some classmates. I'm thinking of awarding a small prize to whoever interoperates with largest number of other students in the class.

7. What to hand in

Take screenshots of your sender and receiver in action in the following cases. In each case, your sender and receiver should print out the messages noted above (i) when they first being execution, (ii) when they've established a channel via the gaia server, and (iii) when they're done, and print out reliable data transfer statistics.

1) Set channel loss and delay at zero, but channel corruption to a non-zero value in both directions. Set the channel corruption level high enough so that both sender and receiver receive at least two corrupted messages during execution.

2) Set channel corruption and delay at zero, but channel loss to a non-zero value Set the channel corruption loss level high enough so that both sender timeouts out and retransmits at least two times.
3) Set channel corruption and loss to zero, but use a high channel delay and a small timeout so that your protocol times out at least two times (note that since no messages are lost or corrupted, these would be pre-mature timeouts).
4) Your sender interoperating with another student's receiver. You should send this screen shot to the other students, so they can hand it in, and they should send you their screenshot so you can hand that in along with your screenshot here.,
5) Your client interoperating with another student's sender. You should send this screen shot to the other students, so they can hand it in, and they should send you their screenshot so you can hand that in along with your screenshot here.

Also, include text that explains what these two screenshots are doing.

- Put all these screenshots into a pdf file (with the description for each screenshot) and upload the file to GradeScope. Please remember to tag each scenario to the questions correctly on GradeScope.
- Zip your sender and receiver code and name the zip file as PA2.zip. Upload the zip file to GradeScope. Due to using auto-grading, make sure that filenames are exactly the same as what is mentioned here.

Programming Language

A note on programming languages:

- You are encouraged to write your client and server in Python 3 since that's the language used in our textbook for sockets. But you can also write it in Java or C if you prefer.

Grading rubric

We'll run the python code that you submit (both client and server) and connect them to each other via the gaia server. We'll also look at the screenshots that you submit in the written document.

Grading rubric TBA