ASSIGNMENT 2: TRIVIAL FILE TRANSFER PROTOCOL (TFTP) REPORT

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1) Introduction

"TFTP is a very simple protocol used to transfer files. It is from this that its name comes, Trivial File Transfer Protocol or TFTP. Each nonterminal packet is acknowledged separately."[1]

The objective of this assignment is to implement a simplified version of the TFTP Protocol based on RFC 1350[2], one that supports only octet mode, handles only a `FILE_NOT_FOUND` error, and without support for error handling in data duplicates. The TFTP server implemented shall be able to handle read and write requests with multiple clients simultaneously with the protocol built on top of UDP i.e. connectionless. As per 1350 requirements, the master port of the Server side is port 69 which shall receive all read and write requests from clients, which will itself generate one slave socket with a port number between 1024 and 49151 inclusive (ports below 1024 are the Well Known Ports and above 49151 are Dynamic ports, both unsuitable for stable usage). The default data size for each DATA packet contents is 512 bytes as per 1350, not including space taken by the opcode and block number (4 bytes). The maximum size of the transmitted file is about 32 MB since each DATA packet is 512 bytes and there are only (255 * 256 + 255 + 1 = 65536) block numbers available. This document shall be used in conjunction with the comments written in the source codes to explain the logic behind the code design.

[1] Sollins, K. "The TFTP Protocol (Revision 2)", *Request For Comments: 1350,* MIT, published July 1992. www.ietf.org/rfc/rfc1350.txt. Accessed 2020-07-04. pp. 1
[2] Ibid.

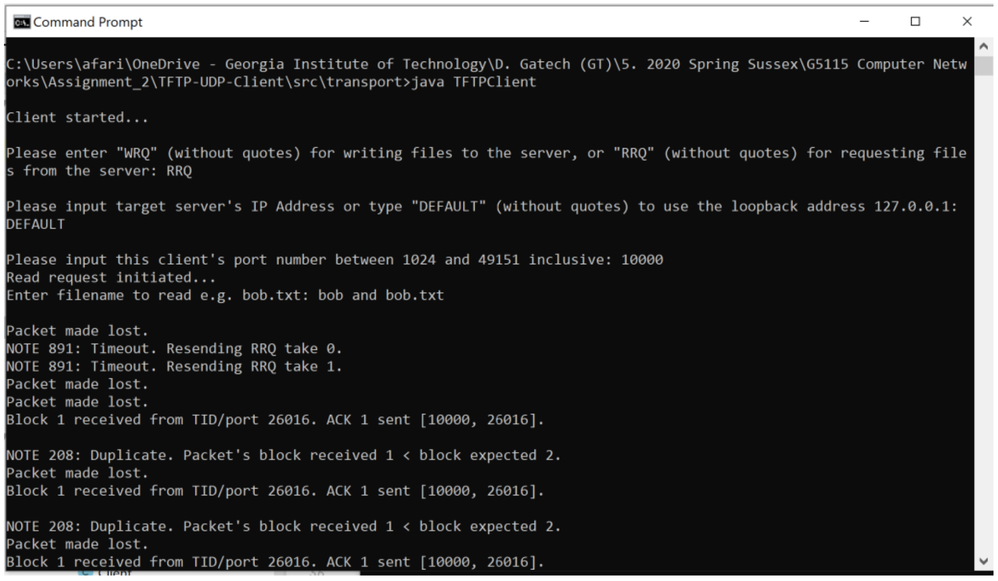
2) Client-Side

Front End

Each client can only communicate with one server at a time. The Client shall start by prompting the user for (1) the main request whether a write or read request, (2) the Internet address of the remote Server which can be the `DEFAULT` loopback address 127.0.0.1, (3) the intended port number of this Client, accepting any number between 1024 and 49151 inclusive, and (4) the name of the file, including name extension, in request e.g. `bob.txt`.

Back End – Read Request

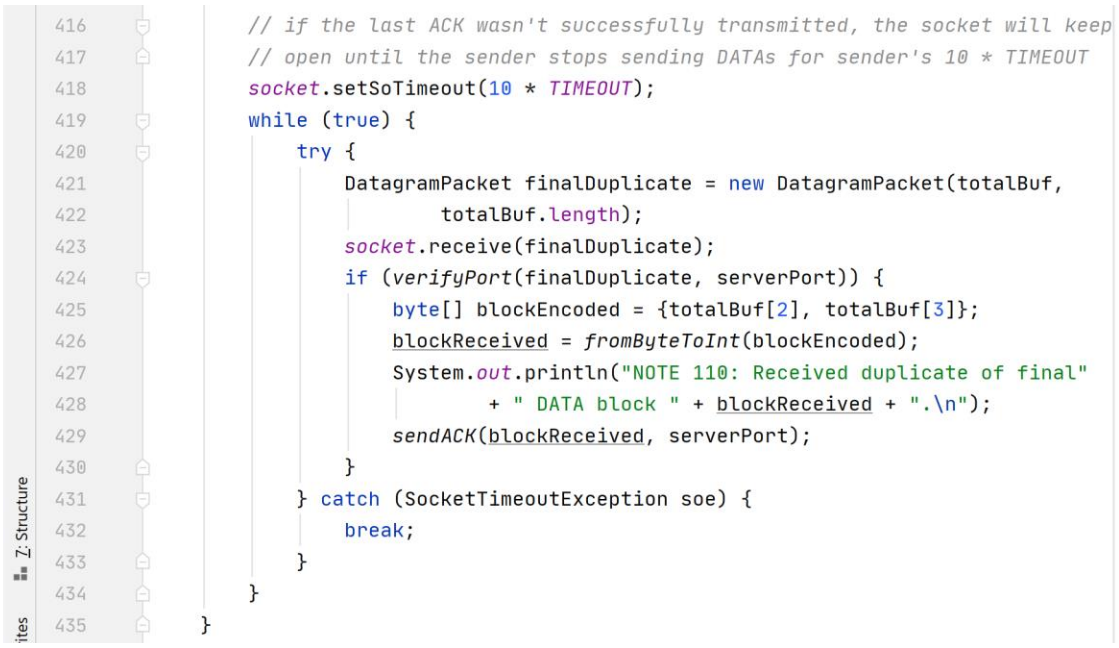
What follows is a series of messages in the command prompt about the status of the transfer, as seen in *Figure 2.1* if the request is a read request (RRQ) and the file requested is `bob and bob.txt`. With the first DATA packet, received by the Client, containing the first `DEFAULT_DATA_SIZE` (512 bytes) of the file successfully sent, the first acknowledgment packet (ACK 1) should be sent to the Server with block number matching the received DATA block number. This signals the Client is ready to accept subsequent DATA blocks. Being aware of the possibility of packet losses (in this program, losses are simulated using a random number generator that randomly skips `DatagramSocket.send(),` the default value `LOSS_PROBABILITY` being 0.0 for no losses), an ACK will be sent again if a duplicate block is received until the Server sends the next block.



```
C:\Users\afari\OneDrive - Georgia Institute of Technology\D. Gatech (GT)\5. 2020 Spring Sussex\G5115 Computer Netw
orks\Assignment_2\TFTP-UDP-Client\src\transport>java TFTPClient

Client started...

Please enter "WRQ" (without quotes) for writing files to the server, or "RRQ" (without quotes) for requesting file
s from the server: RRQ

Please input target server's IP Address or type "DEFAULT" (without quotes) to use the loopback address 127.0.0.1:
DEFAULT

Please input this client's port number between 1024 and 49151 inclusive: 10000
Read request initiated...
Enter filename to read e.g. bob.txt: bob and bob.txt

Packet made lost.
NOTE 891: Timeout. Resending RRQ take 0.
NOTE 891: Timeout. Resending RRQ take 1.
Packet made lost.
Packet made lost.
Block 1 received from TID/port 26016. ACK 1 sent [10000, 26016].

NOTE 208: Duplicate. Packet's block received 1 < block expected 2.
Packet made lost.
Block 1 received from TID/port 26016. ACK 1 sent [10000, 26016].

NOTE 208: Duplicate. Packet's block received 1 < block expected 2.
Packet made lost.
Block 1 received from TID/port 26016. ACK 1 sent [10000, 26016].
```

Figure 2.1 Command Prompt of Client Status

This process repeats until the last DATA block is received (content size of 0 to 511 bytes). The last ACK will be sent with the arrival of the final DATA block (the first and its duplicates) until timeout of the Client's socket occurs at `10 * TIMEOUT` (default value of `TIMEOUT` is 100 ms), the code shown in *Figure 2.2*. This practice of waiting after sending the final ACK is called "dallying".

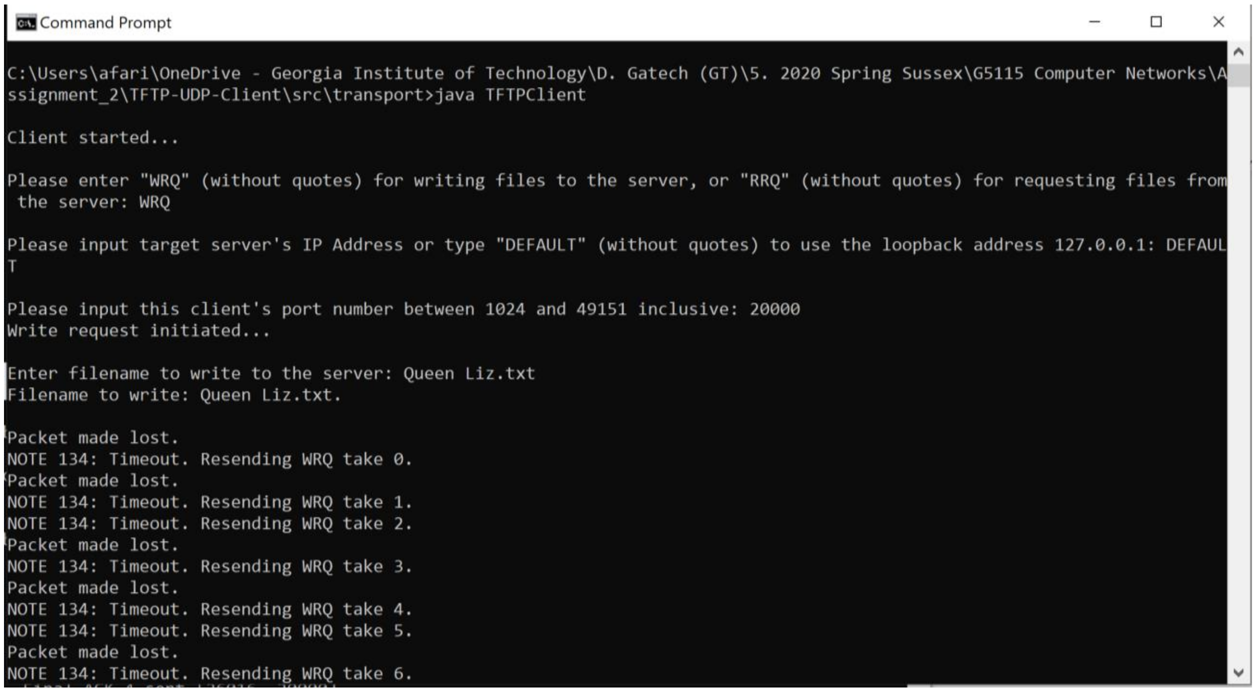


```
        // if the last ACK wasn't successfully transmitted, the socket will keep
        // open until the sender stops sending DATAs for sender's 10 * TIMEOUT
        socket.setSoTimeout(10 * TIMEOUT);
        while (true) {
            try {
                DatagramPacket finalDuplicate = new DatagramPacket(totalBuf,
                        totalBuf.length);
                socket.receive(finalDuplicate);
                if (verifyPort(finalDuplicate, serverPort)) {
                    byte[] blockEncoded = {totalBuf[2], totalBuf[3]};
                    blockReceived = fromByteToInt(blockEncoded);
                    System.out.println("NOTE 110: Received duplicate of final"
                            + " DATA block " + blockReceived + ".\n");
                    sendACK(blockReceived, serverPort);
                }
            } catch (SocketTimeoutException soe) {
                break;
            }
        }
    }
```

Figure 2.2 Client undergoing timeout at the end of a read request.

Back End – Write Request

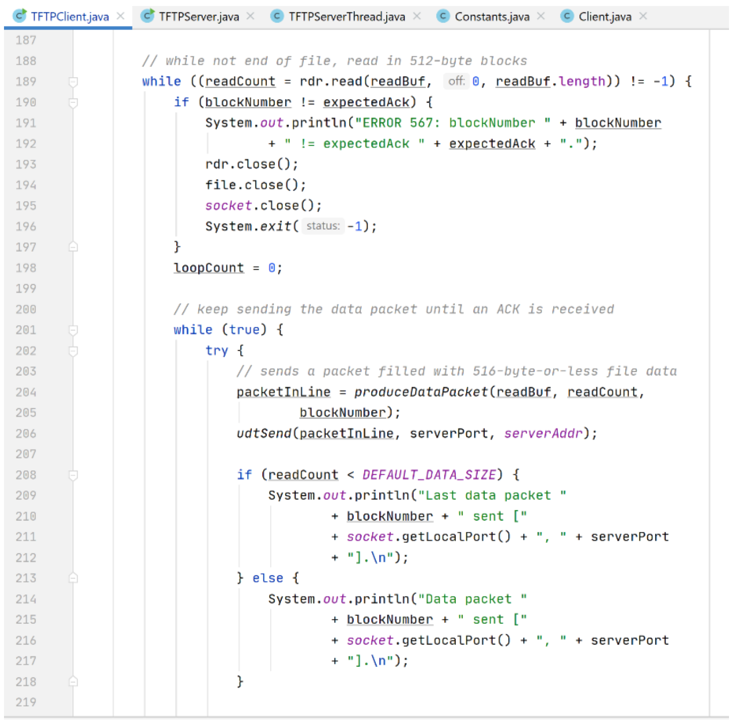
In an opposite scenario, the Client may ask for a write request (WRQ) to write files onto the Server. The 4 inputs are requested and verified, and like an RRQ, the WRQ is sent repeatedly (up to `CLIENT_BRAKE` or 100 times when it is presumed Server is permanently unresponsive) until the Server acknowledges the request with the first ACK (block number 0) to write the file. This initial process is shown in *Figure 2.3* with `Queen Liz.txt` as the file to be written. After each DATA block sent, the respective ACK will be expected; the same DATA block will be sent again after each `TIMEOUT` indefinitely until the ACK is received.



```
C:\Users\afari\OneDrive - Georgia Institute of Technology\D. Gatech (GT)\5. 2020 Spring Sussex\G5115 Computer Networks\A
ssignment_2\TFTP-UDP-Client\src\transport>java TFTPClient

Client started...

Please enter "WRQ" (without quotes) for writing files to the server, or "RRQ" (without quotes) for requesting files from
 the server: WRQ

Please input target server's IP Address or type "DEFAULT" (without quotes) to use the loopback address 127.0.0.1: DEFAUL
T

Please input this client's port number between 1024 and 49151 inclusive: 20000
Write request initiated...

Enter filename to write to the server: Queen Liz.txt
Filename to write: Queen Liz.txt.

Packet made lost.
NOTE 134: Timeout. Resending WRQ take 0.
Packet made lost.
NOTE 134: Timeout. Resending WRQ take 1.
NOTE 134: Timeout. Resending WRQ take 2.
Packet made lost.
NOTE 134: Timeout. Resending WRQ take 3.
Packet made lost.
NOTE 134: Timeout. Resending WRQ take 4.
NOTE 134: Timeout. Resending WRQ take 5.
Packet made lost.
NOTE 134: Timeout. Resending WRQ take 6.
```

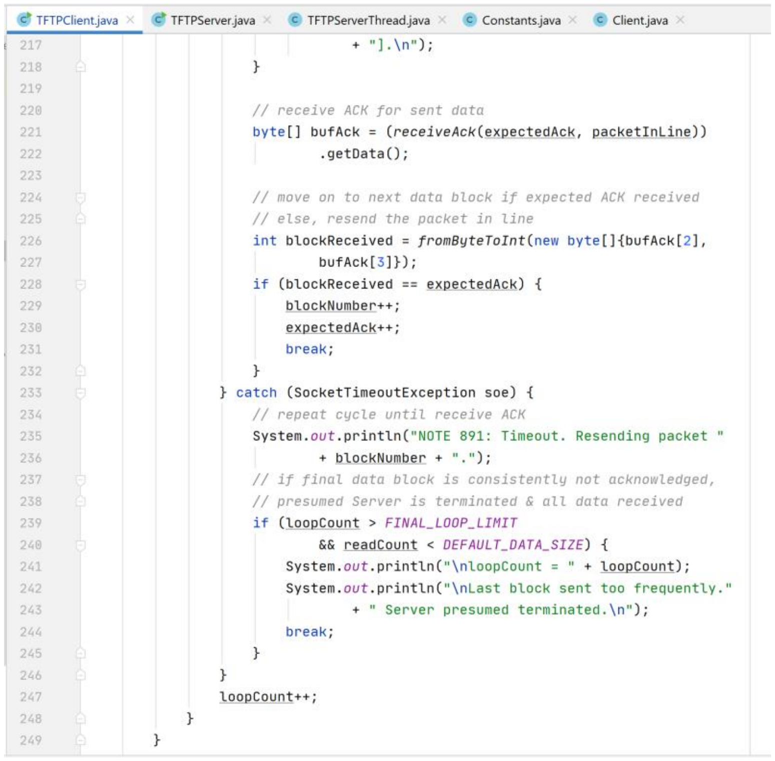
Figure 2.3 Initial process of a WRQ in Client-side

To send the file, the file is first broken into pieces that fit into the DATA packets. More formally, a `BufferedReader` is used to read buffer the contents of the file and is read 512 bytes (or less if the end of file is reached) at a time. Those 512 bytes are packed into a DATA packet, constructed with the DATA opcode and the current block number (`blockNumber`) to go through an unreliable-data-transfer sending process i.e. through `udtSend(DatagramPacket, int, InetAddress)`, as shown in *Figure 2.4*. The same DATA packet will be sent after each timeout of the client socket indefinitely until the correct acknowledgment is received (ACK's block number `blockReceived` equal to expected block number `expectedAck`). In *Figure 2.5*, `receiveAck(int, DatagramPacket)` acts to receive any packets that arrive in the Client socket, which also (a) verifies the source internet socket address, (b) verifies the packet is an ACK, (c) checks if the received ACK number is expected, and either (i) resend the previous DATA packet if a previous ACK is received, or (ii) returns the received ACK if the correct is received. To account the possibility the Server terminates connection before the last ACK could be received, the Client will automatically terminate after attempting to send the final DATA `FINAL_LOOP_LIMIT` or 20 times without receiving the last ACK.



```java

        // while not end of file, read in 512-byte blocks
        while ((readCount = rdr.read(readBuf, off: 0, readBuf.length)) != -1) {
            if (blockNumber != expectedAck) {
                System.out.println("ERROR 567: blockNumber " + blockNumber
                        + " != expectedAck " + expectedAck + ".");
                rdr.close();
                file.close();
                socket.close();
                System.exit( status: -1);
            }
            loopCount = 0;

            // keep sending the data packet until an ACK is received
            while (true) {
                try {
                    // sends a packet filled with 516-byte-or-less file data
                    packetInLine = produceDataPacket(readBuf, readCount,
                            blockNumber);
                    udtSend(packetInLine, serverPort, serverAddr);

                    if (readCount < DEFAULT_DATA_SIZE) {
                        System.out.println("Last data packet "
                                + blockNumber + " sent ["
                                + socket.getLocalPort() + ", " + serverPort
                                + "].\n");
                    } else {
                        System.out.println("Data packet "
                                + blockNumber + " sent ["
                                + socket.getLocalPort() + ", " + serverPort
                                + "].\n");
                    }

```

Figure 2.4 WRQ: Sending DATA



```java
                                + "].\n");
                    }

                    // receive ACK for sent data
                    byte[] bufAck = (receiveAck(expectedAck, packetInLine))
                            .getData();

                    // move on to next data block if expected ACK received
                    // else, resend the packet in line
                    int blockReceived = fromByteToInt(new byte[]{bufAck[2],
                            bufAck[3]});
                    if (blockReceived == expectedAck) {
                        blockNumber++;
                        expectedAck++;
                        break;
                    }
                } catch (SocketTimeoutException soe) {
                    // repeat cycle until receive ACK
                    System.out.println("NOTE 891: Timeout. Resending packet "
                            + blockNumber + ".");
                    // if final data block is consistently not acknowledged,
                    // presumed Server is terminated & all data received
                    if (loopCount > FINAL_LOOP_LIMIT
                            && readCount < DEFAULT_DATA_SIZE) {
                        System.out.println("\nloopCount = " + loopCount);
                        System.out.println("\nLast block sent too frequently."
                                + " Server presumed terminated.\n");
                        break;
                    }
                }
                loopCount++;
            }
        }
```

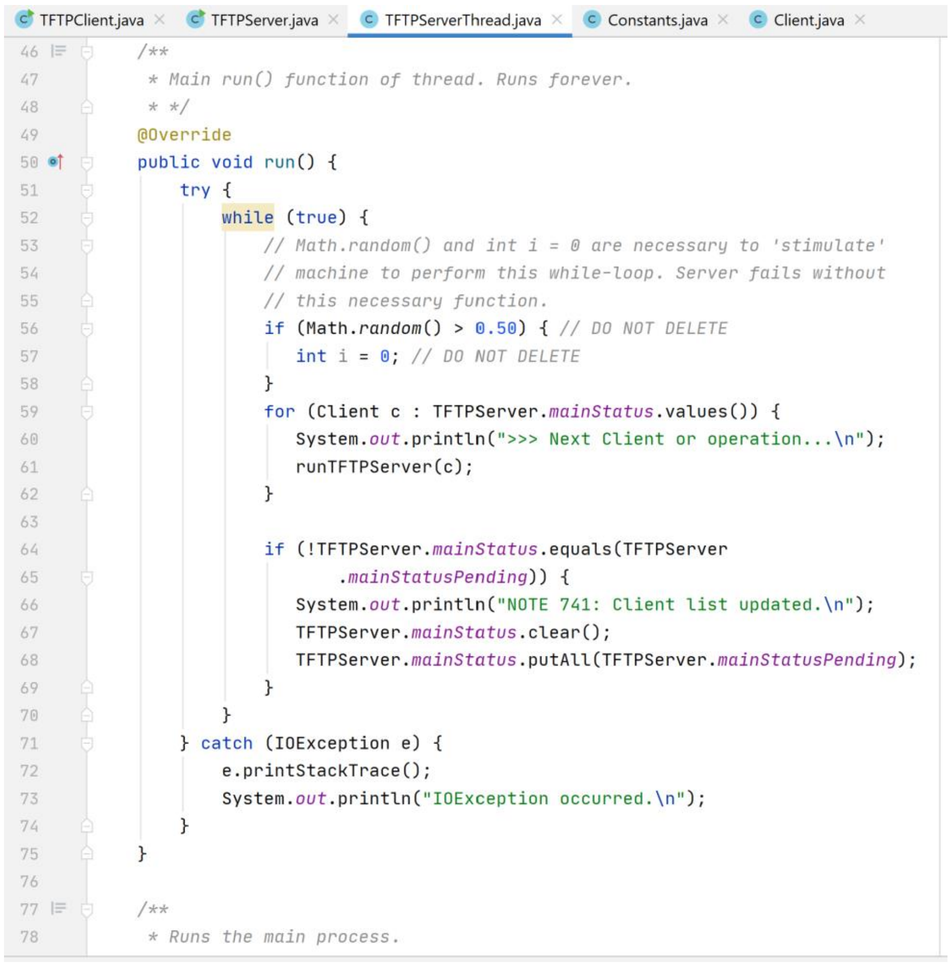
Figure 2.5 WRQ: Receiving ACK

3) Server-Side

Introduction

The Server is more complex than the Client since it is designed to be able to communicate with multiple Clients at one time. No input is requested from the user, unlike the Client side. Constant values are kept separate in `Constants.java`. The Server keeps track of all current `Client` objects, each a separate instance of the `Client.java` class, and their status in a `HashMap<InetSocket Address, Client>` named `mainStatus` where each Client is identified by its Internet Socket Address. Threading is used here to make two threads: the main Thread in `TFTPServer.java` which will forever listen and accept new requests and the secondary thread in `TFTPServerThread.java` which will forever iterate and loop the `Client` objects in `mainStatus`, triggering one state change in each Client before moving on to the next Client (*Figure 3.1*). If another request arrives from an address already in `mainStatus`, the request is assumed as a duplicate of the old request and ignored.

Clients are added or removed from a shadow of `mainStatus` called `mainStatusPending.` `mainStatus` updates the list of Clients for processing from `mainStatusPending` only after each Client has completed one state change to prevent a `ConcurrentModificationException`.



TFTPClient.java | TFTPServer.java | TFTPServerThread.java | Constants.java | Client.java

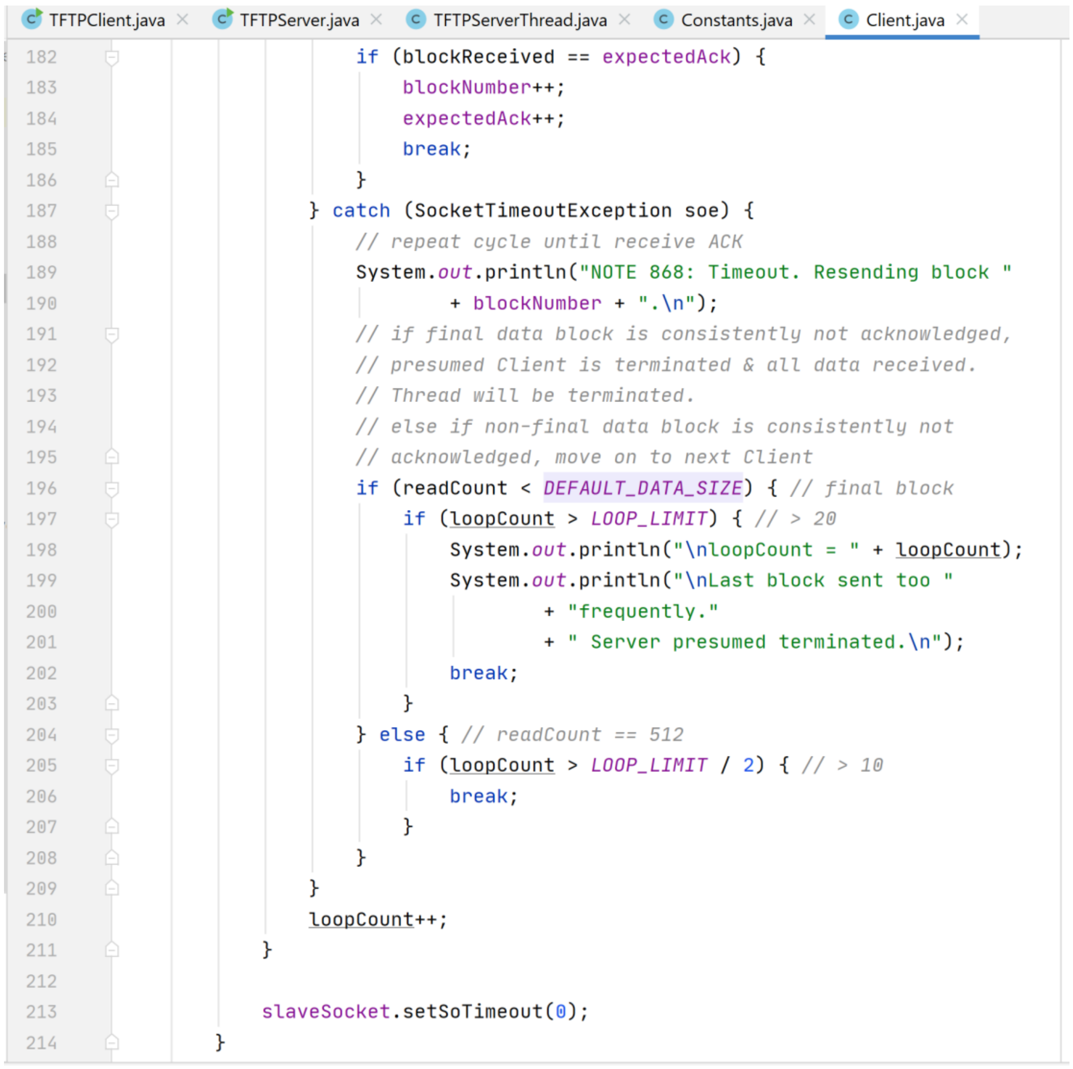
```java
    /**
     * Main run() function of thread. Runs forever.
     * */
    @Override
    public void run() {
        try {
            while (true) {
                // Math.random() and int i = 0 are necessary to 'stimulate'
                // machine to perform this while-loop. Server fails without
                // this necessary function.
                if (Math.random() > 0.50) { // DO NOT DELETE
                    int i = 0; // DO NOT DELETE
                }
                for (Client c : TFTPServer.mainStatus.values()) {
                    System.out.println(">>> Next Client or operation...\n");
                    runTFTPServer(c);
                }

                if (!TFTPServer.mainStatus.equals(TFTPServer
                        .mainStatusPending)) {
                    System.out.println("NOTE 741: Client list updated.\n");
                    TFTPServer.mainStatus.clear();
                    TFTPServer.mainStatus.putAll(TFTPServer.mainStatusPending);
                }
            }
        } catch (IOException e) {
            e.printStackTrace();
            System.out.println("IOException occurred.\n");
        }
    }

    /**
     * Runs the main process.
```

Figure 3.1 Server triggering process for each Client

Back End – Read Request

For each Client in `mainStatus`, this thread will first check the request of the Client. If it is an RRQ, the file will be checked if it exists in the database (when `blockNumber` in process is 1). A `FILE_NOT_FOUND` error is sent if file not found, else a `readRequestServer(DatagramPacket)` method will be called to trigger the change from the first to the second state involving making a buffer to read the file, and sending DATA 1 repeatedly until ACK 1 is received. This process returns and the next Client will be processed and repeats for subsequent DATA blocks. If the file size is a multiple of 512 bytes, then a final DATA packet with zero content will be sent until either (i) the final ACK is received, or (ii) if the final DATA packet has been sent 20 times (`LOOP_LIMIT`), both triggering the removal of this Client from `mainStatus` and ends the processing for this Client's request. Like the Client's write request, a `BufferedReader` is used to send the file contents in 512 bytes of DATA packets.

Since the Server may be processing multiple Clients, a limit is placed on the number of allowed attempts as shown in *Figure 3.2* at an amount half of `LOOP_LIMIT` or 10 attempts. If the same DATA packet has been sent without its acknowledgment received 10 times, the process returns, and `TFTPServerThread.java` will process the next `Client` object.



```
                    if (blockReceived == expectedAck) {
                        blockNumber++;
                        expectedAck++;
                        break;
                    }
                } catch (SocketTimeoutException soe) {
                    // repeat cycle until receive ACK
                    System.out.println("NOTE 868: Timeout. Resending block "
                            + blockNumber + ".\n");
                    // if final data block is consistently not acknowledged,
                    // presumed Client is terminated & all data received.
                    // Thread will be terminated.
                    // else if non-final data block is consistently not
                    // acknowledged, move on to next Client
                    if (readCount < DEFAULT_DATA_SIZE) { // final block
                        if (loopCount > LOOP_LIMIT) { // > 20
                            System.out.println("\nloopCount = " + loopCount);
                            System.out.println("\nLast block sent too "
                                    + "frequently."
                                    + " Server presumed terminated.\n");
                            break;
                        }
                    } else { // readCount == 512
                        if (loopCount > LOOP_LIMIT / 2) { // > 10
                            break;
                        }
                    }
                }
                loopCount++;
            }

            slaveSocket.setSoTimeout(0);
        }
```

Figure 3.1 RRQ: Limit placed on the number of allowed attempts for each block

Hence, the definition of a ‘change of state’ in RRQ, i.e. the completion of which will end the processing for this Client, can be either:

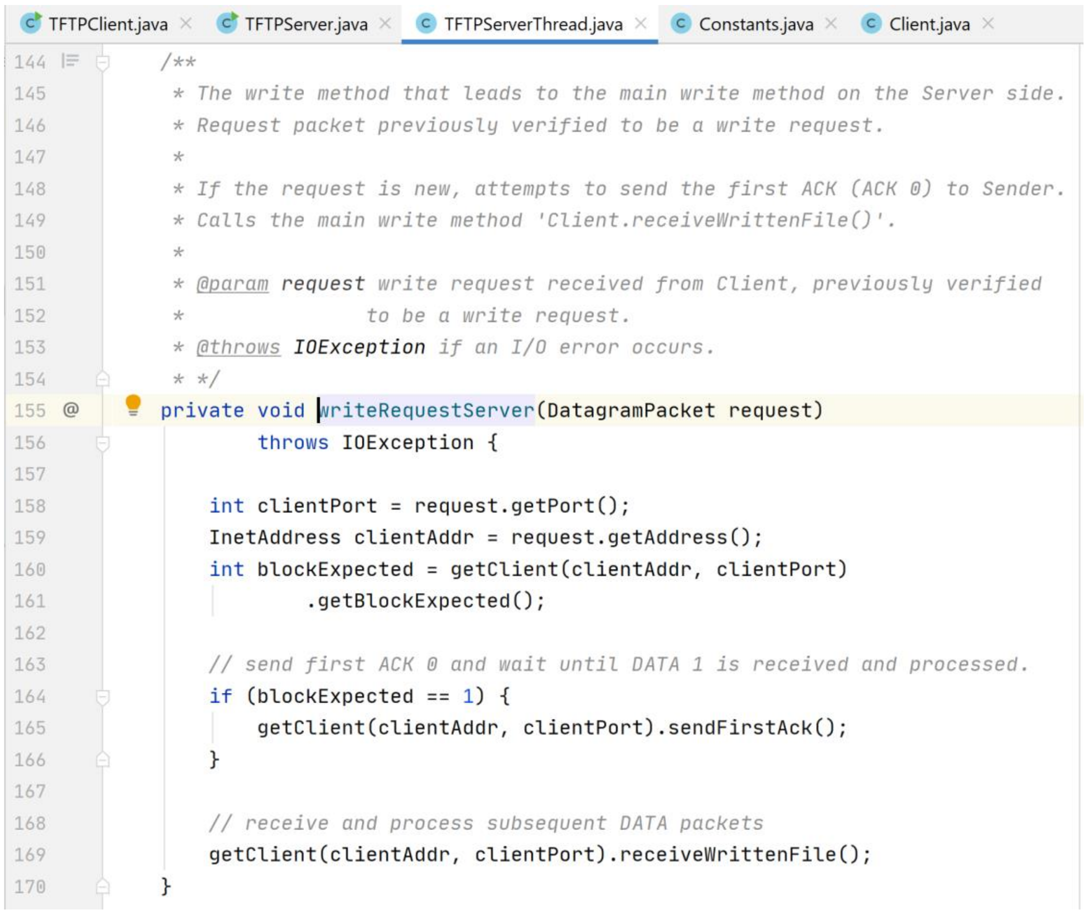
a) If the `blockNumber` is 1 when the request is new, (1) checking the file exists in the database, (2) initializing the `BufferedReader` for reading the file in 512-byte blocks, (3) sending the first DATA packet up to `LOOP_LIMIT` / 2 times or until the respective ACK is received, in that order assuming file exists; or
b) If `blockNumber` = *x* > 1, sending DATA *x* packet up to `LOOP_LIMIT` / 2 times or until ACK *x* is received; or
c) If the final DATA block (content < 512 bytes) is being sent and packet content size is not a multiple of 512 bytes, either (i) sending the last DATA packet up to `LOOP_LIMIT`, or (ii) receiving the last ACK before the 21st DATA packet is sent*; or
d) If the final DATA block is being sent and file size is a multiple of 512 bytes, either (i) a final DATA block with zero content is sent up to `LOOP_LIMIT` times, or (ii) receiving the last ACK before the 21st zero DATA packet is sent*.

* the completion of causes the Client to be removed from further processing.

Back End – Write Request

The WRQ process in the Server-side is roughly like the Client’s Read Request in that the file will be received in 512-byte DATA blocks with an ACK sent to acknowledge each block before the next DATA block is sent.

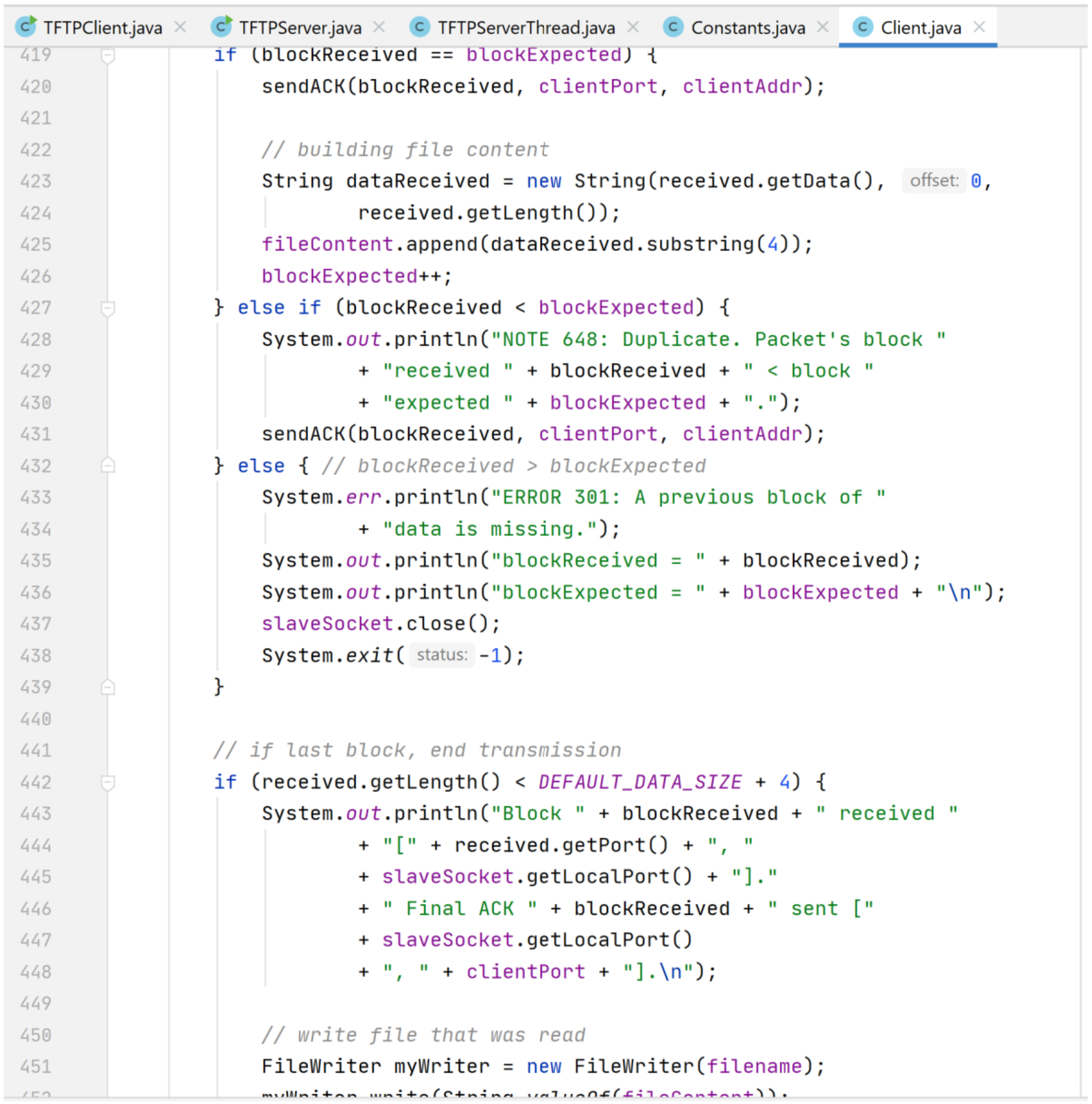
If the request is new and no ACK was sent yet i.e. `expectedBlock` = 1, the first ACK (ACK 0) is sent once to the Client as an acknowledgment of the request and to begin sending DATA packets. The Server calls the main write process to handle each incoming DATA packets as shown in *Figure 3.2*.



```java
/**
 * The write method that leads to the main write method on the Server side.
 * Request packet previously verified to be a write request.
 *
 * If the request is new, attempts to send the first ACK (ACK 0) to Sender.
 * Calls the main write method 'Client.receiveWrittenFile()'.
 *
 * @param request write request received from Client, previously verified
 *                to be a write request.
 * @throws IOException if an I/O error occurs.
 * */
private void writeRequestServer(DatagramPacket request)
        throws IOException {

    int clientPort = request.getPort();
    InetAddress clientAddr = request.getAddress();
    int blockExpected = getClient(clientAddr, clientPort)
            .getBlockExpected();

    // send first ACK 0 and wait until DATA 1 is received and processed.
    if (blockExpected == 1) {
        getClient(clientAddr, clientPort).sendFirstAck();
    }

    // receive and process subsequent DATA packets
    getClient(clientAddr, clientPort).receiveWrittenFile();
}
```

Figure 3.2 Leading to main write request for the Client

In the main write process `Client.receiveWrittenFile()`, ACK 0 will be sent after each timeout until DATA 1 is received. As each DATA packet is received, the contents are appended to a `StringBuilder` instance and the respective ACK sent. Any duplicate DATAs are responded with their respective ACKs and contents are ignored. As shown in *Figure 3.3*, after the final DATA is received, the final ACK is sent and a `FileWriter` initialized to write the file into Server.



```java
if (blockReceived == blockExpected) {
    sendACK(blockReceived, clientPort, clientAddr);

    // building file content
    String dataReceived = new String(received.getData(), offset: 0,
            received.getLength());
    fileContent.append(dataReceived.substring(4));
    blockExpected++;
} else if (blockReceived < blockExpected) {
    System.out.println("NOTE 648: Duplicate. Packet's block "
            + "received " + blockReceived + " < block "
            + "expected " + blockExpected + ".");
    sendACK(blockReceived, clientPort, clientAddr);
} else { // blockReceived > blockExpected
    System.err.println("ERROR 301: A previous block of "
            + "data is missing.");
    System.out.println("blockReceived = " + blockReceived);
    System.out.println("blockExpected = " + blockExpected + "\n");
    slaveSocket.close();
    System.exit( status: -1);
}

// if last block, end transmission
if (received.getLength() < DEFAULT_DATA_SIZE + 4) {
    System.out.println("Block " + blockReceived + " received "
            + "[" + received.getPort() + ", "
            + slaveSocket.getLocalPort() + "]."
            + " Final ACK " + blockReceived + " sent ["
            + slaveSocket.getLocalPort()
            + ", " + clientPort + "].\n");

    // write file that was read
    FileWriter myWriter = new FileWriter(filename);
    myWriter.write(String.valueOf(fileContent));
```

Figure 3.3 WRQ: Server receiving DATA and responding with ACKs

But to account the possibility the final ACK did not reach the Client, the process sets a Boolean value `writeRequestCompleted` to true. This Boolean value keeps the slave port open for 10 * `TIMEOUT` to receive final DATA duplicates and respond appropriately until timeout when the Client is removed from further processing. Hence, a 'change of state' in a write request is either:

a) If the first DATA is to be received (`blockExpected` = 1), send the first ACK 0 repeatedly until DATA 1 is received, appending contents to `StringBuilder`, send ACK 1; or

b) If `blockExpected` = *x* > 1 and the correct block number *x* is received, sending ACK *x*, appending its contents, and to receive the next DATA *x* + 1 packet (waiting indefinitely); or
c) If `blockExpected` = *x* > 1 and a duplicate block *x* – 1 is received, sending ACK *x* – 1; or
d) The final DATA packet is received, and the file is successfully written; or
e) Keeping slave socket open for `10 * TIMEOUT` to receive and acknowledge duplicates of the last DATA, timeout triggers removal of Client from further processing.

Acknowledgments

The writer would like to thank Dr. Parisis, Wikipedia, and Google for providing advice throughout the creation of this protocol.