TCP/IP Data Transmission

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1 Summary

Today we introduce the TCP/IP, a standard communication network protocol commonly used when communicating over the internet and other computer networks. The TCP/IP protocol guarantees the message being sent by a server is received by a client without error. We will look at a simple application of the protocol using a PIC32 Microcontroller Unit (MCU) as a server and a Windows machine as a client. By analyzing the raw Ethernet frame transmission of the TCP/IP messages we better the understanding of how TCP/IP successfully transmits data. The analysis of the frames show how a client first establishes a socket connection to a server, then sends a command to the server, and finally completes the communication medium by waiting for a response back from the server. The TCP/IP protocol has some overhead messages on top of the messages sent by the client to ensure data integrity on both sides.

2 Introduction

The TCP/IP stack is an internet protocol that sets a standard for computers to communicate over an inter-connected network. Starting a communication channel requires a server and a client. The server is setup to listen for connection requests from clients. When a connection attempt is seen the server accepts and establishes a connection to the client. The client can then request information from the server over the established connection.

The information is sent using the established TCP/IP protocol. TCP/IP is a five layered modular protocol. Each part is independent from the other allowing for the different pieces to be updated to newer standards without having to update the entire protocol. The highest abstraction of the TCP/IP protocol is the application layer. In the application layer we see how a typical user interacts with the communication protocol. You may be familiar with HTTP, SSH, or FTP which are all application layer protocols.

The application layer hands off communication to the transport layer which appends a TCP header to the transmission. The TCP header contains information such as a data checksum, destination port, and priority pointer to the transmission. In short the TCP header ensure the transmission between the server and client arrives in prompt and correct fashion. With the TCP header attached to our data our data unit is now named a segment.

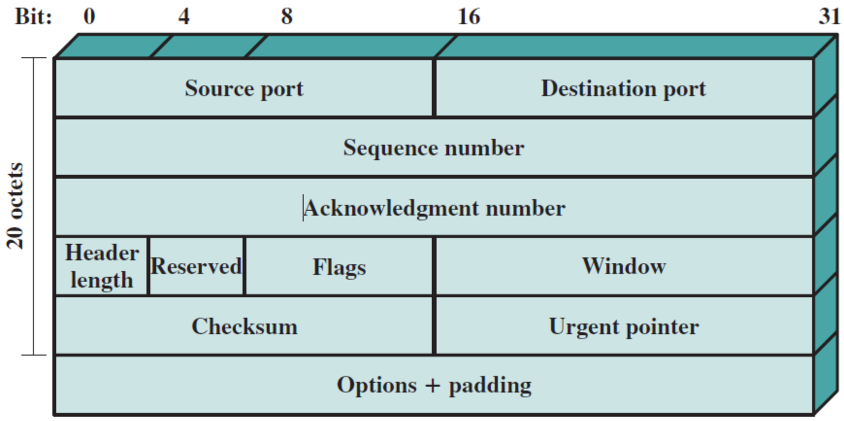


Figure 1: TCP Header [1]

Next down in the TCP/IP protocol stack is the internet layer. Inside the internet layer we append a routing header which tells the packet where to go using an IP address (a logical address). An IP address can be either 32 bits (IPv4) or 128 bits (IPv6) in length. The IP standard also allocates space in the header for time to live information.

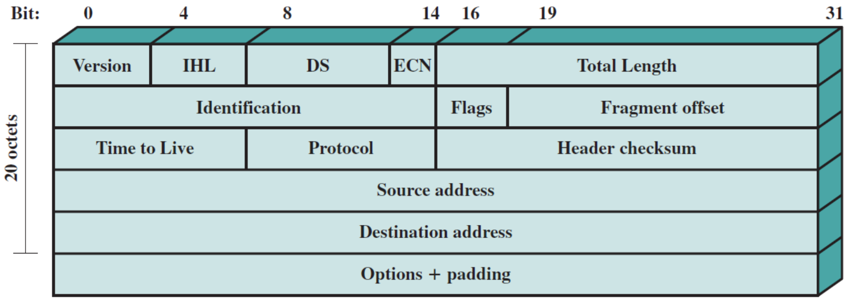


Figure 2: IPv4 Header [1]

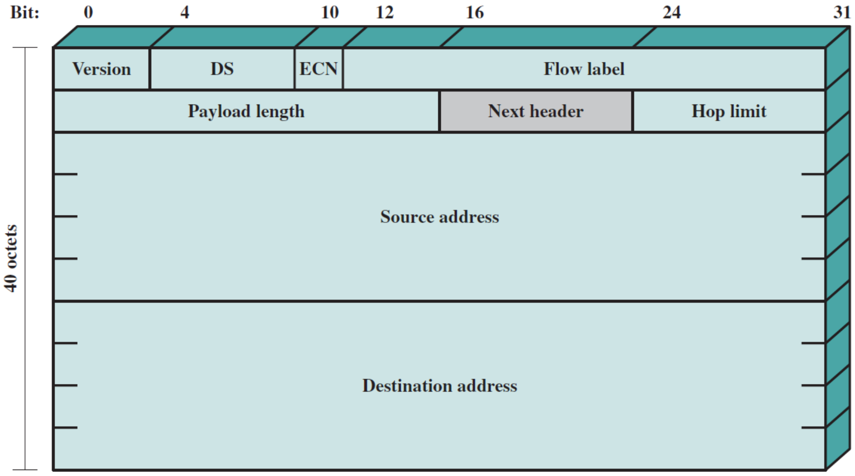


Figure 3: IPv6 Header [1]

At this point our information is called an IP packet. An IP packet transforms to a frame with the inclusion of a network access/data link header. This header contains maps the logical address to a physical address within in the network. The different data link standards you may be familiar with include Ethernet, Wi-Fi or ATM.

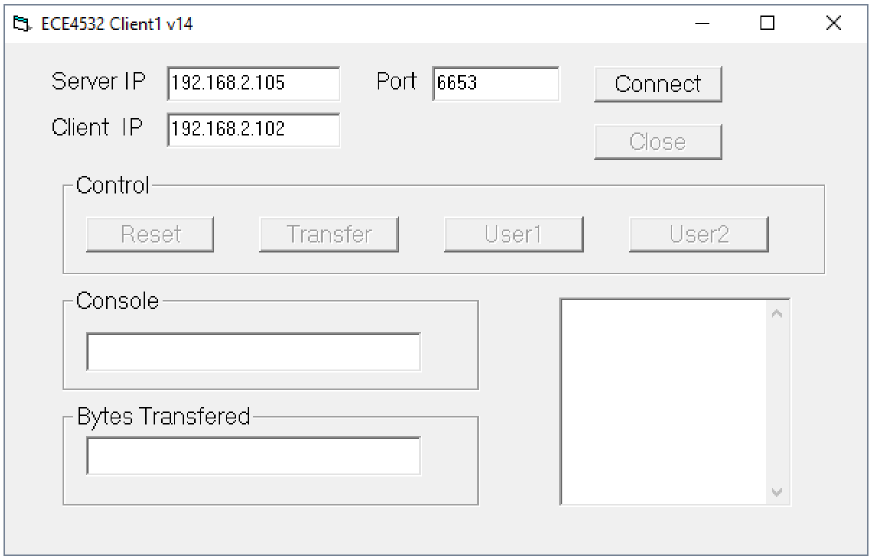
At this level in the stack we reach the bottom most layer called the physical layer. The physical layer is consist of the twister pair, fiber or microwave communication methods commonly used to transmit data between two locations.

In this project we will investigate the process of using the TCP/IP protocol for data communication between a Windows 10 desktop and a Microchip PIC32 microcontroller unit (MCU). Our PIC32 will serve as our server machine and the desktop will be our client. We will interact with TCP/IP using a precompile Visual Basic (VB) application. Our server will use a preloaded C program to provide information requested from our VB application - there is no server side application. We will use Wireshark, a network protocol analyzer program, to identify packets as they cross through our network to see the raw TCP/IP frames. We will identify the blocks that make up our transmission.

3 Discussion

We begin by programing our PIC32 MCU with server code that is built to interact with our VB application. To begin we need to setup our sockets to use the TCP/IP protocol and luckily in C there are predefined variables that allow us to specify how we will use a TCP, and IPv4 header. Since we are using IPv4 we need to define the servers IP address. Line 34 defines the servers static IP of 192.168.2.105. Addressing the TCP header is seen in line 73 when we tell our socket to use the $SOCK\_STREAM$ pre-defined header. $SOCK\_STREAM$ is a predefined data type that initializes our TCP header. Shortly following our $SOCK\_STREAM$ definition we specify the socket to monitor port 6643 for connections attempts being made by our client machine. Defining these constants we now have set our server to listen for incoming connections and accept any attempts made a by client. After the handshake between server and client is established we use the $recvfrom$ C function to receive information requests from the client.

Moving over to our client machine we go to the network configuration set it to have a static IP of 192.168.2.102. We are using the precompiled VB program as our application level interaction between the server and client. We know from setting up the server that our server IP is 192.168.2.105 and sever listening port is 6653. By pressing the *Connect* button we create a socket and connect to our server on the client side.

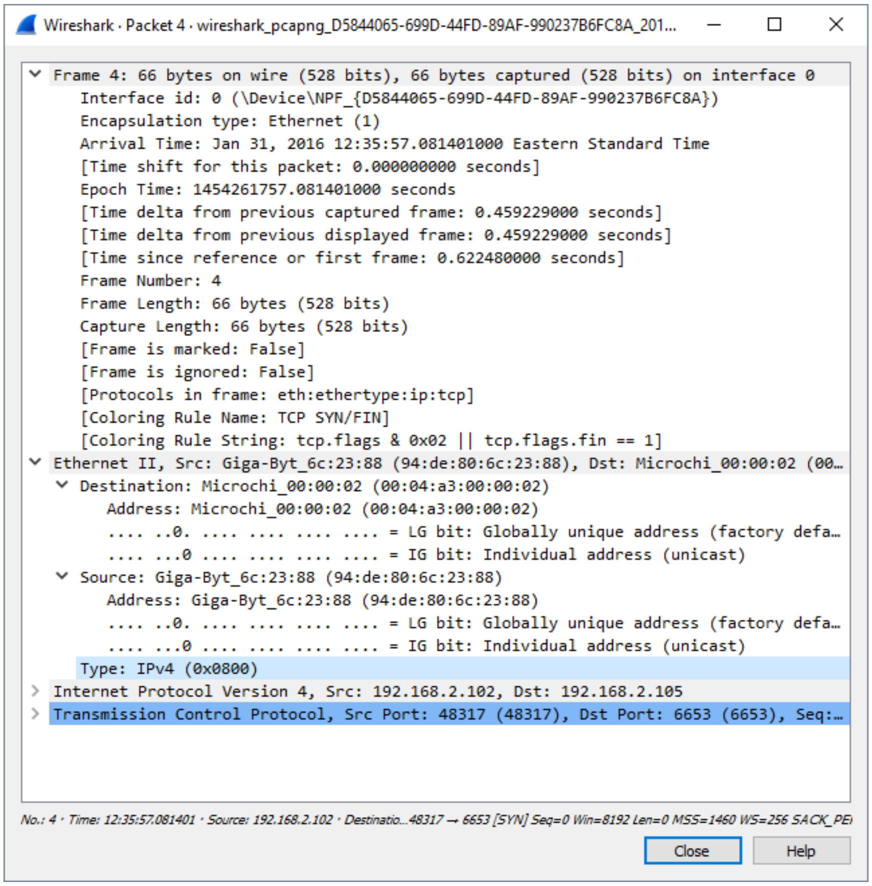


Server IP 192.168.2.105 Port 6653

Client IP 192.168.2.102

Figure 4: Client Side VB Program Initial Setup

Upon connection attempt we see all three LEDs on our PIC32 board sequentially flash. This behavior was defined in our C program which we loaded onto the PIC32 board earlier. Moving to the Wireshark program we can see the two packets over our network showing the interaction between client and server.



Wireshark · Packet 4 · wireshark_pcapng_D5844065-699D-44FD-89AF-990237B6FC8A_201...

```
Frame 4: 66 bytes on wire (528 bits), 66 bytes captured (528 bits) on interface 0
    Interface id: 0 (\Device\NPF_{D5844065-699D-44FD-89AF-990237B6FC8A})
    Encapsulation type: Ethernet (1)
    Arrival Time: Jan 31, 2016 12:35:57.081401000 Eastern Standard Time
    [Time shift for this packet: 0.000000000 seconds]
    Epoch Time: 1454261757.081401000 seconds
    [Time delta from previous captured frame: 0.459229000 seconds]
    [Time delta from previous displayed frame: 0.459229000 seconds]
    [Time since reference or first frame: 0.622480000 seconds]
    Frame Number: 4
    Frame Length: 66 bytes (528 bits)
    Capture Length: 66 bytes (528 bits)
    [Frame is marked: False]
    [Frame is ignored: False]
    [Protocols in frame: eth:ethertype:ip:tcp]
    [Coloring Rule Name: TCP SYN/FIN]
    [Coloring Rule String: tcp.flags & 0x02 || tcp.flags.fin == 1]
Ethernet II, Src: Giga-Byt_6c:23:88 (94:de:80:6c:23:88), Dst: Microchi_00:00:02 (00…
    Destination: Microchi_00:00:02 (00:04:a3:00:00:02)
        Address: Microchi_00:00:02 (00:04:a3:00:00:02)
        .... ..0. .... .... .... .... = LG bit: Globally unique address (factory defa…
        .... ...0 .... .... .... .... = IG bit: Individual address (unicast)
    Source: Giga-Byt_6c:23:88 (94:de:80:6c:23:88)
        Address: Giga-Byt_6c:23:88 (94:de:80:6c:23:88)
        .... ..0. .... .... .... .... = LG bit: Globally unique address (factory defa…
        .... ...0 .... .... .... .... = IG bit: Individual address (unicast)
    Type: IPv4 (0x0800)
Internet Protocol Version 4, Src: 192.168.2.102, Dst: 192.168.2.105
Transmission Control Protocol, Src Port: 48317 (48317), Dst Port: 6653 (6653), Seq:…
```

```
No.: 4 · Time: 12:35:57.081401 · Source: 192.168.2.102 · Destinatio...48317 → 6653 [SYN] Seq=0 Win=8192 Len=0 MSS=1460 WS=256 SACK_PE
```

Figure 5: Client → Sever Frame Analysis

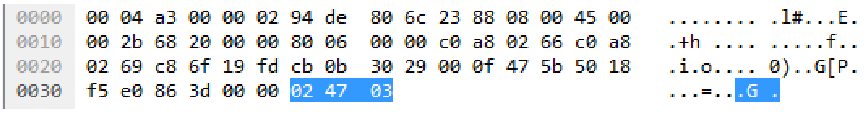
By clicking connect on our sever we initiated a TCP packet to our server. We can see first and foremost that 66 bytes were sent in this frame over the Ethernet protocol. At the data-link layer we can see the physical MAC addressing of the destination MicroChip PIC32 MCU $00 : 04 : a3 : 00 : 00 : 02$ server and source Gigabyte Manufactured client machine $94 : de : 80 : 6c : 23 : 88$.

Moving up to the internet layer we can see the logical IPv4 mapping to the server destination 192.168.2.105 from our client machine 192.168.2.102. Moving up to the transport layer we see the segment is using the TCP protocol to send the data. The request on the client sever originated from port 48317 and was sent to the PIC32 sever port 6653 as specified in our VBapplication.

Moving back to our VB application we have two more control buttons; Reset and Transfer. To understand the operation of these two buttons we move back to our sever source code. Inside our sever-side code we are interested in looking at line 115. Here we use the $recvfrom$ function to store our received data seen on our predefined socket $StreamSock$ into the buffer $rbfr$. We set the output of $recvfrom$ to $rlen$ which we will use to check the size of received data. If $rlen$ equals zero it means the client closed the socket connection. If $rlen$ is less than zero it means there was an error in the connection and the connection to the client was lost. If $rlen$ is greater than zero it means the client sent some data which we will wish to read.

To check what was sent by the client we have look at the first byte in the transmission.

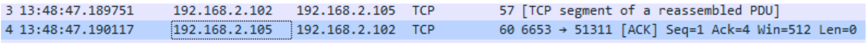
If the received message starts with 2 we know the sent data is the start of a transmission. If the second byte is 71 we say the message sent by the client was a global reset. The global reset status sent by the client prompts the sever PIC32 board to blink LED1. We can test the function by hitting reset in the VB application and monitoring the output on Wireshark. We can see the reset call sent out by the VB application by looking at the raw HEX values inside the packet. The first 54 octets of the packet are reserved for headers that make up our resulting transmission frame. The last 3 octets in the frame make up the data of our transmission. Note how the transmission begins with the expected 02. We then see a $0x47$ which translates to a 71 in decimal. The message in this frame is to tell the server to reset the connection.



```
0000  00 04 a3 00 00 02 94 de  80 6c 23 88 08 00 45 00   ........ .l#...E.
0010  00 2b 68 20 00 00 80 06  00 00 c0 a8 02 66 c0 a8   .+h .... .....f..
0020  02 69 c8 6f 19 fd cb 0b  30 29 00 0f 47 5b 50 18   .i.o.... 0)..G[P.
0030  f5 e0 86 3d 00 00 02 47  03                        ...=...G .
```

Figure 6: Wireshark RAW HEX of Frame Sent on Reset

The server responds to the client by sending an ACK or Acknowledgment packet back. The ACK packet tells the client machine that the server successfully received the message. If an ACK was not seen the client would start retransmission of the reset packet.



```
3 13:48:47.189751    192.168.2.102  192.168.2.105  TCP       57 [TCP segment of a reassembled PDU]
4 13:48:47.190117    192.168.2.105  192.168.2.102  TCP       60 6653 → 51311 [ACK] Seq=1 Ack=4 Win=512 Len=0
```

Figure 7: Wireshark Packet Listing of ACK packet.

If the second byte in the received buffer $rbfr$ is equal to 84 we say the client sent a transfer request. The transfer request prompts the PIC32 board to start generating 1296 bytes worth and load it into our transport buffer $tbfr$. The actual loop will generate an array of numbers from zero to one thousand two hundred ninety-six. It is shown in both decimal and hex in table 1.

tbfr	***Decimal***	***HEX***
tbfr [0:1]	01	0x0001
tbfr [2:3]	03	0x0003
tbfr [254:255]	255	0x00FF
tbfr [256:257]	0257	0x0001
tbfr [1293:1294]	01293	0x000D
tbfr [1295:1296]	01295	0x000F

Table 1: tbfr Tx Data Generated by PIC32

References

[1] JW. Stallings, Data and Computer Communications, Person Education Inc. , 2014.