



College of Engineering, Design and Physical Science
Electronic and Computer Engineering

Assignment **Java Testing and Measuring**

Distributed Computing Systems Engineering Msc

Author: Christoph Gschrey

Lab-Partner: Matthias Gebert

Date: 22. September 2017

Supervisor: Prof. Dr. Peter Väterlein

ASSIGNMENT SUBMISSION FORM

Please note: that no course work will be accepted without this cover sheet.

Please ensure: that you keep a copy of work submitted and retain your receipt in case of query.

Student Number:	SPO ID Number (Office use only):	
Course:		Level:

MODULE	
Module Code:	Module Title:
Lab / Assignment:	Deadline:
Lab group (if applicable):	Date Stamp (Office use only):
Academic Responsible:	
Administrator:	

Please note: that detailed feedback will be provided on a feedback form.

✂.....

RECEIPT SECTION (Office Copy)	
Student Number:	SPO ID Number (Office use only):
Student First Name:	Student Last Name:
Module Code:	Module Title:
Lab / Assignment:	
Lab group (if applicable):	Deadline:
Academic Responsible:	Number of Days late:

DECLARATION	
I have read and I understand the guidelines on plagiarism and cheating in the Handbook and I certify that my contribution to this report fully complies with these guidelines. I confirm that I have kept a copy of my work and that I have not lent my work to any other students.	
Signed:	Date Stamp (Office use only):

✂.....

RECEIPT SECTION (Student Copy)	
Student Number:	Student Name:
Lab / Assignment:	
Lab group (if applicable):	Module Title:
Academic Responsible:	Deadline:
Module Code:	Date Stamp (Office use only):

The University penalty system will be applied to any work submitted late.

IMPORTANT: You **MUST** keep this receipt in a safe place as you may be asked to produce it at any time as proof of submission of the assignment. Please submit this form with the assignment attached to the Department of Design Education Office in the Michael Sterling Building, room MCST 055.

Contents

1	Introduction	1
2	IP/ICMP analysis	2
2.1	Node configuration	3
2.2	Subnet internal IP Destination	4
2.2.1	a) Basic PING command	5
2.2.2	b) PING command with large data package	8
2.2.3	c) PING command with 'don't fragment' flag	11
2.3	Subnet external IP Destination	11
2.3.1	d) Basic PING command with destination in another subnet	12
2.3.2	e) PING command with reduced 'time to live'	16
2.3.3	f) PING command with timestamps	19
2.4	ARP analysis	22
2.4.1	a) Deleting the ARP cache	22
2.4.2	b) Shutting down one PC	22
2.4.3	c) Reconnect after Reboot	22
2.5	IP multicast addressing	22
3	TCP analysis	23
3.1	Traffic generator handling	23
3.2	Simple TCP Communication	23
3.2.1	Connection establishment	23
3.2.2	Data transfer	23
3.2.3	Connection release	23
3.3	TCP flow control	23
3.4	TCP transmission error recovery/abort	23
3.5	TCP protocol errors (synchronization errors)	23
4	IPv6/ICMPv6 analysis	24
4.1	Node configuration	24
4.1.1	IPv4 and IPv6 configuration	24
4.1.2	interfaces for IPv6	24
4.2	PING commands	24
4.2.1	a) Basic ICMPv6 PING command	24
4.2.2	b) ICMPv6 PING command with large data package	24

4.2.3	c) Rebooting PC	24
4.2.4	d) Enforcing Neighbor discovery	24
4.2.5	e) ICMPv6 PING command with destination in another subnet	24
4.2.6	f) PING to a remote tunnel end	24
5	Conclusion	25
	Bibliography	26

1 Introduction

The following report refers to the Computer network assignment and is structured into three parts. The first part's topic is an analysis of the network protocols ICMP and IP (both v4), while the second part covers the exercises related to TCP. The final chapter describes the exercises for the new versions of ICMP and IP (v6). These exercises were done together with my lab-partner Antonio Parotta.

2 IP/ICMP analysis

In this first part of the laboratory the program Wireshark was used to capture and analyse packages of different network protocols. The traffic was generated by PING-commands to send the observable packages from one lab PC to another. The following network protocols were analyzed:

- Internet Protocol version 4 (IPv4)
- Internet Control Message Protocol version 4 (ICMPv4)
- Address Resolution Protocol (ARP)
- Carrier Sense Multiple Access/Collision Detection (CSMA/CD)

To understand how these protocols work and to be able to explain how they behave in different situations, having a look on the protocol's headers is necessary.

The PING-commands generate packages consisting of different protocol headers and transferable data. Each Ping is transformed into an Ethernet frame containing the IP and ICMP headers. Table ?? is an representation of the basic ICMP Header while Table ?? shows the header for the echo request/reply packages that can be observed via Wireshark when executing the PING-commands.

bits	0-7	8-15	16-23	24-31
bytes	1	2	3	4
offset 0	Type	Code	Checksum	
offset 32	Data			

Table 2.1: ICMP header

bits	0-7	8-15	16-23	24-31
bytes	1	2	3	4
offset 0	Type	Code	Checksum	
offset 32	Identifier		Sequence Number	
offset 64	data			

Table 2.2: ICMP type 8 echo request/reply packet

Table ?? shows the header for the Internet Protocol v4. Noteable here are the entered destination address as well as the source address of the sender. The Time to Live is also an important

segment of the header, which will be significant later on for an specific PING-Command. IP provides the possibility to specify options for the transfered packet. This will also be used in one of the PING-Commands.

bits	0-3	4-7	8-11	12-15	16-18	19-23	24-27	28-31
bytes	1	2	3	4	5	6	7	8
offset 0	Version	IHL	Type of Service		Total Length			
offset 32	Identification				Flags	Fragment Offset		
offset 64	Time to Live		Protocol		Header Checksum			
offset 96	Source Address							
offset 128	Destination Address							
offset 160	Options							

Table 2.3: IPv4 Header

Table ?? shows the abstract Ethernet II frame. This frame contains the MAC-addresses for source and destination, a type segment as well as the checksum for the frame. Interesting here is the Payload field. This segments contains the headers for ICMP and IP as well as the transferable data. The maximal size for this segment is 1500 bytes for one packet. But because is must contain the headers for each networking protocol (ICMP and IP), it can't be fully occupied by transferable data. This is why the Maximum Transmission Unit (MTU) is smaller. It is only 1472 bytes, because the size of the headers must be subtracted from the payload field.

$$\text{MTU} = \text{Payload} - \text{IP Header} - \text{ICMP Header}$$

$$1500 \text{ byte} - 20 \text{ byte} - 8 \text{ byte} = 1472 \text{ byte}$$

Size in bit	24	24	8	184-6000	16
Size in byte	6	6	2	46 - 1500	4
Frame segments	Destination Address	Source Address	Type	Payload (Data)	FCS

Table 2.4: Ethernet II frame

2.1 Node configuration

Figure 2.1 shows the node configuration and settings for the computer used for the exercises in this workshop:

```

Ethernet-Adapter IPv4-priv:
  Verbindungsspezifisches DNS-Suffix:
  IPv4-Adresse . . . . . : 192.168.31.6
  Subnetzmaske . . . . . : 255.255.255.0
  Standardgateway . . . . . :

Ethernet-Adapter IPv4-pub:
  Verbindungsspezifisches DNS-Suffix: rznt.rzdir.fht-esslingen.de
  Verbindungslokale IPv6-Adresse . . : fe80::6051:d005:7784:47fd%11
  IPv4-Adresse . . . . . : 134.108.8.37
  Subnetzmaske . . . . . : 255.255.252.0
  Standardgateway . . . . . : 134.108.11.254

Ethernet-Adapter VMware Network Adapter VMnet1:
  Verbindungsspezifisches DNS-Suffix:
  Verbindungslokale IPv6-Adresse . . : fe80::38b3:236d:ff8:8a19%16
  IPv4-Adresse . . . . . : 192.168.110.1
  Subnetzmaske . . . . . : 255.255.255.0
  Standardgateway . . . . . :

Ethernet-Adapter VMware Network Adapter VMnet8:
  Verbindungsspezifisches DNS-Suffix:
  Verbindungslokale IPv6-Adresse . . : fe80::811e:824c:7506:61c8%17
  IPv4-Adresse . . . . . : 192.168.71.1
  Subnetzmaske . . . . . : 255.255.255.0
  Standardgateway . . . . . :

Ethernet-Adapter VirtualBox Host-Only Network:
  Verbindungsspezifisches DNS-Suffix:
  Verbindungslokale IPv6-Adresse . . : fe80::4917:2bb5:aa97:a5fa%19
  IPv4-Adresse . . . . . : 192.168.56.1
  Subnetzmaske . . . . . : 255.255.255.0
  Standardgateway . . . . . :

Ethernet-Adapter IPv6:
  Verbindungsspezifisches DNS-Suffix:
  IPv6-Adresse . . . . . : 2001:7c0:c00:19d:3c3d:b555:99e1:2a35
  Verbindungslokale IPv6-Adresse . . : fe80::3c3d:b555:99e1:2a35%12
  Standardgateway . . . . . : fe80::2e0:29ff:fe24:f2be%12

```

Figure 2.1: Node configuration for 134.108.8.37

2.2 Subnet internal IP Destination

In the first exercise we created traffic by using the PING-Command to send packets to another PC within the same subnet. Figure 2.2 shows the simplified architecture for this environment:

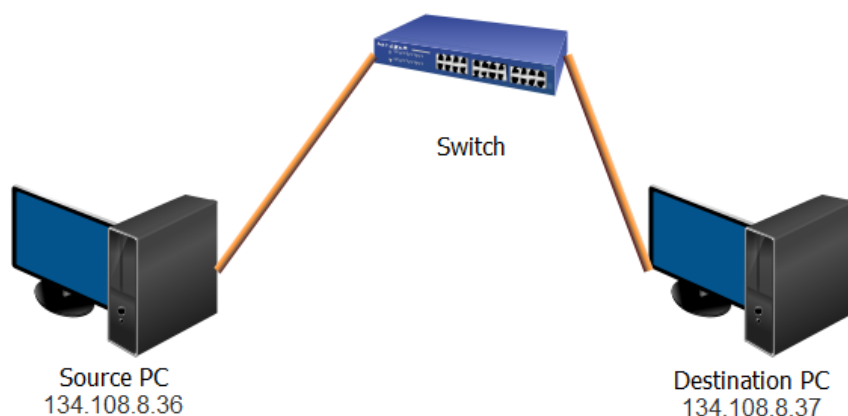


Figure 2.2: Source and Destination PC connected with a switch in the network lab

2.2.1 a) Basic PING command

The first task was sending a basic ping from one PC to another within the same subnet and capturing the sent packets using Wireshark. The PING-Command was:

```
ping -n 1 -l 64 134.108.8.37
```

Listing ?? shows the Wireshark trace for the captured packets. For this simple PING command, two ICMP packet were captured. One ICMP echo request was send from the source PC to the Destination PC and after this the Destination PC answers with an ICMP echo reqly. Both packets contain the Ethernet II frame as well as the IP and ICMP headers as discussed in chapter 2. Each packet has the source and destination address from the IP header as well as same sequence number. The total size of each packet is 106. It contains the source and target MAC-addresses from the Ethernet frame (both 6 byte), the type of the Ethernet frame (2 byte), the IP-header (20 byte), the ICMP-header (8 byte) and the transmitted data (64 byte).

No.	Time	Source	Destination	Protocol	Length	Info
445	32.125568	134.108.8.36	134.108.8.37	ICMP	106	Echo (ping) request id=0x0001 , seq=25/6400, ttl=128 (reply in 448)
Frame 445: 106 bytes on wire (848 bits), 106 bytes captured (848 bits) on interface 0						
Interface id: 0 (\Device\NPF_{55902047-E973-4FFC-B9C0-B0FAC2DA73AF})						
Interface name: \Device\NPF_{55902047-E973-4FFC-B9C0-B0FAC2DA73AF}						
Encapsulation type: Ethernet (1)						
Arrival Time: Nov 17, 2017 09:46:22.558509000 Mitteleuropäische Zeit						
[Time shift for this packet: 0.000000000 seconds]						
Epoch Time: 1510908382.558509000 seconds						
[Time delta from previous captured frame: 0.000092000 seconds]						
[Time delta from previous displayed frame: 0.000000000 seconds]						
[Time since reference or first frame: 32.125568000 seconds]						
Frame Number: 445						
Frame Length: 106 bytes (848 bits)						
Capture Length: 106 bytes (848 bits)						
[Frame is marked: True]						
[Frame is ignored: False]						
[Protocols in frame: eth:ethertype:ip:icmp:data]						
[Coloring Rule Name: ICMP]						
[Coloring Rule String: icmp || icmpv6]						
Ethernet II, Src: Dell_87:b7:aa (90:b1:1c:87:b7:aa), Dst: Dell_88:97:76 (90:b1:1c:88:97:76)						
Destination: Dell_88:97:76 (90:b1:1c:88:97:76)						
Address: Dell_88:97:76 (90:b1:1c:88:97:76)						
....0. = LG bit: Globally unique address (factory default)						
....0 = IG bit: Individual address (unicast)						
Source: Dell_87:b7:aa (90:b1:1c:87:b7:aa)						

```

    Address: Dell\_87:b7:aa (90:b1:1c:87:b7:aa)
29     .... ..0. .... = LG bit: Globally unique address (factory default)
    .... ..0 .... = IG bit: Individual address (unicast)
31   Type: IPv4 (0x0800)
Internet Protocol Version 4, Src: 134.108.8.36, Dst: 134.108.8.37
33   0100 .... = Version: 4
    .... 0101 = Header Length: 20 bytes (5)
35   Differentiated Services Field: 0x00 (DSCP: CS0, ECN: Not-ECT)
    0000 00.. = Differentiated Services Codepoint: Default (0)
37   .... ..00 = Explicit Congestion Notification: Not ECN-Capable Transport (0)
    Total Length: 92
39   Identification: 0x30fb (12539)
    Flags: 0x00
41   0... .... = Reserved bit: Not set
    .0... .... = Don't fragment: Not set
43   ..0. .... = More fragments: Not set
    Fragment offset: 0
45   Time to live: 128
    Protocol: ICMP (1)
47   Header checksum: 0xec84 [validation disabled]
    [Header checksum status: Unverified]
49   Source: 134.108.8.36
    Destination: 134.108.8.37
51   [Source GeoIP: Unknown]
    [Destination GeoIP: Unknown]
53 Internet Control Message Protocol
    Type: 8 (Echo (ping) request)
55   Code: 0
    Checksum: 0x856a [correct]
57   [Checksum Status: Good]
    Identifier (BE): 1 (0x0001)
59   Identifier (LE): 256 (0x0100)
    Sequence number (BE): 25 (0x0019)
61   Sequence number (LE): 6400 (0x1900)
    [Response frame: 448]
63   Data (64 bytes)

65 0000 61 62 63 64 65 66 67 68 69 6a 6b 6c 6d 6e 6f 70 abcdefghijklmnop
    0010 71 72 73 74 75 76 77 61 62 63 64 65 66 67 68 69 qrstuvwabcdefghi
67 0020 6a 6b 6c 6d 6e 6f 70 71 72 73 74 75 76 77 61 62 jklmnopqrstuvwxyzab
    0030 63 64 65 66 67 68 69 6a 6b 6c 6d 6e 6f 70 71 72 cdefghijklmnopqr
69   Data: 6162636465666768696a6b6c6d6e6f707172737475767761...
    [Length: 64]
71
No.      Time          Source          Destination    Protocol Length Info
73 448 32.125797    134.108.8.37    134.108.8.36    ICMP      106    Echo (ping) reply id=0x0001,
    seq=25/6400, ttl=128 (request in 445)

75 Frame 448: 106 bytes on wire (848 bits), 106 bytes captured (848 bits) on interface 0
    Interface id: 0 (\\Device\\NPF_{55902047-E973-4FFC-B9C0-B0FAC2DA73AF})

```

```

77      Interface name: \\Device\\NPF_{55902047-E973-4FFC-B9C0-B0FAC2DA73AF}
      Encapsulation type: Ethernet (1)
79      Arrival Time: Nov 17, 2017 09:46:22.558738000 Mitteleuropäische Zeit
      [Time shift for this packet: 0.000000000 seconds]
81      Epoch Time: 1510908382.558738000 seconds
      [Time delta from previous captured frame: 0.000005000 seconds]
83      [Time delta from previous displayed frame: 0.000229000 seconds]
      [Time since reference or first frame: 32.125797000 seconds]
85      Frame Number: 448
      Frame Length: 106 bytes (848 bits)
87      Capture Length: 106 bytes (848 bits)
      [Frame is marked: True]
89      [Frame is ignored: False]
      [Protocols in frame: eth:ethertype:ip:icmp:data]
91      [Coloring Rule Name: ICMP]
      [Coloring Rule String: icmp || icmpv6]
93      Ethernet II, Src: Dell_88:97:76 (90:b1:1c:88:97:76), Dst: Dell_87:b7:aa (90:b1:1c:87:b7:aa)
      Destination: Dell_87:b7:aa (90:b1:1c:87:b7:aa)
95          Address: Dell_87:b7:aa (90:b1:1c:87:b7:aa)
          .... 0. .... = LG bit: Globally unique address (factory default)
97          .... 0 .... = IG bit: Individual address (unicast)
      Source: Dell_88:97:76 (90:b1:1c:88:97:76)
99          Address: Dell_88:97:76 (90:b1:1c:88:97:76)
          .... 0. .... = LG bit: Globally unique address (factory default)
101          .... 0 .... = IG bit: Individual address (unicast)
      Type: IPv4 (0x0800)
103      Internet Protocol Version 4, Src: 134.108.8.37, Dst: 134.108.8.36
          0100 .... = Version: 4
105          .... 0101 = Header Length: 20 bytes (5)
          Differentiated Services Field: 0x00 (DSCP: CS0, ECN: Not-ECT)
107          0000 00.. = Differentiated Services Codepoint: Default (0)
          .... 00 = Explicit Congestion Notification: Not ECN-Capable Transport (0)
109      Total Length: 92
          Identification: 0x3021 (12321)
111      Flags: 0x00
          0... .... = Reserved bit: Not set
113          .0.. .... = Don't fragment: Not set
          ..0. .... = More fragments: Not set
115      Fragment offset: 0
          Time to live: 128
117      Protocol: ICMP (1)
          Header checksum: 0x0000 [validation disabled]
119          [Header checksum status: Unverified]
          Source: 134.108.8.37
121          Destination: 134.108.8.36
          [Source GeoIP: Unknown]
123          [Destination GeoIP: Unknown]
      Internet Control Message Protocol
125      Type: 0 (Echo (ping) reply)
          Code: 0

```

```

127    Checksum: 0x8d6a [correct]
      [Checksum Status: Good]
129    Identifier (BE): 1 (0x0001)
      Identifier (LE): 256 (0x0100)
131    Sequence number (BE): 25 (0x0019)
      Sequence number (LE): 6400 (0x1900)
133    [Request frame: 445]
      [Response time: 0.229 ms]
135    Data (64 bytes)

137 0000 61 62 63 64 65 66 67 68 69 6a 6b 6c 6d 6e 6f 70 abcdefghijklmnop
      0010 71 72 73 74 75 76 77 61 62 63 64 65 66 67 68 69 qrstuvwabcdefghi
139 0020 6a 6b 6c 6d 6e 6f 70 71 72 73 74 75 76 77 61 62 jklmnopqrstuvwxyz
      0030 63 64 65 66 67 68 69 6a 6b 6c 6d 6e 6f 70 71 72 cdefghijklmnopqr
141    Data: 6162636465666768696a6b6c6d6e6f707172737475767761...
      [Length: 64]

```

Listing 2.1: Wireshark trace for simple PING command

2.2.2 b) PING command with large data package

For the second exercise we had to execute a PING-Command with a very large data package of 2000 byte. The PING-Command was:

```
ping -n 1 -l 2000 134.108.8.36
```

Figure 2.3 shows the console output for this ping:

```

C:\Users\rn-labor>ping -n 1 -l 2000 134.108.8.36
Ping wird ausgeführt für 134.108.8.36 mit 2000 Bytes Daten:
Antwort von 134.108.8.36: Bytes=2000 Zeit<1ms TTL=128

Ping-Statistik für 134.108.8.36:
    Pakete: Gesendet = 1, Empfangen = 1, Verloren = 0
    (0% Verlust),
    Ca. Zeitangaben in Millisek.:
    Minimum = 0ms, Maximum = 0ms, Mittelwert = 0ms

```

Figure 2.3: Console output for PING-Command with 2000 bytes data

It seems that the protocol ICMP does not have any problems with this as the console output shows no warning. IP however does have a problem with this large packet size. As the data exceeds the Maximum Transmission Unit, the packet must be fragmented and separated into two packets. The following listing is shortened, but shows the four packages sent between both lab-PCs:

,

No.	Time	Source	Destination	Protocol	Length	DestPort	Info
				Delta Time			
2	236 0.000000	134.108.8.37	134.108.8.36	ICMP	1514		Echo (ping) request id=0 x0001, seq=25/6400, ttl=128 (reply in 240) 0.000000
4	Frame 236: 1514 bytes on wire (12112 bits), 1514 bytes captured (12112 bits) on interface 0						
	Interface id: 0 (\\Device\\NPF_{55902047-E973-4FFC-B9C0-BOFAC2DA73AF})						
6	Interface name: \\Device\\NPF_{55902047-E973-4FFC-B9C0-BOFAC2DA73AF}						
	Encapsulation type: Ethernet (1)						
8	Arrival Time: Nov 17, 2017 09:58:38.374317000 Mitteleuropäische Zeit						
	[Time shift for this packet: 0.000000000 seconds]						
10	Epoch Time: 1510909118.374317000 seconds						
	[Time delta from previous captured frame: 0.000024000 seconds]						
12	[Time delta from previous displayed frame: 0.000000000 seconds]						
	[Time since reference or first frame: 36.388239000 seconds]						
14	Frame Number: 236						
	Frame Length: 1514 bytes (12112 bits)						
16	Capture Length: 1514 bytes (12112 bits)						
	[Frame is marked: True]						
18	[Frame is ignored: False]						
	[Protocols in frame: eth:ethertype:ip:icmp:data]						
20	[Coloring Rule Name: ICMP]						
	[Coloring Rule String: icmp || icmpv6]						
22	Ethernet II, Src: 90:b1:1c:88:97:76, Dst: 90:b1:1c:87:b7:aa						
	Destination: 90:b1:1c:87:b7:aa						
24	Address: 90:b1:1c:87:b7:aa						
	.... ..0. = LG bit: Globally unique address (factory default)						
26	.... ..0 = IG bit: Individual address (unicast)						
	Source: 90:b1:1c:88:97:76						
28	Address: 90:b1:1c:88:97:76						
	.... ..0. = LG bit: Globally unique address (factory default)						
30	.... ..0 = IG bit: Individual address (unicast)						
	Type: IPv4 (0x0800)						
32	Internet Protocol Version 4, Src: 134.108.8.37, Dst: 134.108.8.36						
	0100 = Version: 4						
34	.... 0101 = Header Length: 20 bytes (5)						
	Differentiated Services Field: 0x00 (DSCP: CS0, ECN: Not-ECT)						
36	0000 00.. = Differentiated Services Codepoint: Default (0)						
	.... ..00 = Explicit Congestion Notification: Not ECN-Capable Transport (0)						
38	Total Length: 1500						
	Identification: 0x3e7e (15998)						
40	Flags: 0x01 (More Fragments)						
	0... = Reserved bit: Not set						
42	.0.. = Don't fragment: Not set						
	..1. = More fragments: Set						
44	Fragment offset: 0						
	Time to live: 128						
46	Protocol: ICMP (1)						
	Header checksum: 0x0000 [validation disabled]						

```

48 [Header checksum status: Unverified]
Source: 134.108.8.37
50 Destination: 134.108.8.36
[Source GeoIP: Unknown]
52 [Destination GeoIP: Unknown]
Internet Control Message Protocol
54 Type: 8 (Echo (ping) request)
Code: 0
56 Checksum: 0x7b5e [unverified] [fragmented datagram]
[Checksum Status: Unverified]
58 Identifier (BE): 1 (0x0001)
Identifier (LE): 256 (0x0100)
60 Sequence number (BE): 25 (0x0019)
Sequence number (LE): 6400 (0x1900)
62 [Response frame: 240]
Data (1472 bytes)
64
No.      Time      Source      Destination      Protocol Length DestPort Info
Delta Time
66 237 0.000007 134.108.8.37 134.108.8.36 IPv4 562 Fragmented IP protocol (
proto=ICMP 1, off=1480, ID=3e7e) 0.000007

68 No.      Time      Source      Destination      Protocol Length DestPort Info
Delta Time
240 0.000488 134.108.8.36 134.108.8.37 ICMP 1514 Echo (ping) reply id=0
x0001, seq=25/6400, ttl=128 (request in 236) 0.000488
70
No.      Time      Source      Destination      Protocol Length DestPort Info
Delta Time
72 241 0.000002 134.108.8.36 134.108.8.37 IPv4 562 Fragmented IP protocol (
proto=ICMP 1, off=1480, ID=332d) 0.000002

```

Listing 2.2: Wireshark trace for PING command with 2000 bytes data

It can be observed that the first packet occupies all 1514 bytes that can be sent in one ICMP packet. Subtracting the segments from the Ethernet frame (14 byte), the IP-header (20 byte) and the ICMP-header (8 byte), there is room for 1472 byte of raw data. The remaining 528 byte of data can't be transmitted in the same packet. So the data must be fragmented and sent inside another packet. As ICMP doesn't play a role in the fragmentation, it's header isn't needed anymore in the second packet. However the second packet contains the IP-header (20 byte) as it is the protocol that manages the fragmentation and transmission controlling. The segments for the Ethernet frame (14 byte) are also included, because without that there could not be any transmission at all. So summed up the second packet has a size of 562 byte.

2.2.3 c) PING command with 'don't fragment' flag

For this last exercise another PING with 2000 byte of data was executed. But this time the 'don't fragment' flag **-f** was set:

```
ping -n 1 -l 2000 134.108.8.36 -f
```

This causes a problem, because as discussed in the previous chapter this large amount of data cannot be transmitted in one single packet. So IP needs to fragment it into two separate packets. But in this case it receives the 'don't fragment' command. This contradicts the functionality of IP and it throws an error that ICMP recognizes and displays a message in the console:

```
C:\Users\rn-labor>ping -n 1 -l 2000 134.108.8.36 -f
Ping wird ausgeführt für 134.108.8.36 mit 2000 Bytes Daten:
Paket müsste fragmentiert werden, DF-Flag ist jedoch gesetzt.
Ping-Statistik für 134.108.8.36:
    Pakete: Gesendet = 1, Empfangen = 0, Verloren = 1
    (100% Verlust),
```

Figure 2.4: Console output for PING-Command with 2000 bytes data

There is no Wireshark trace for this exercise, because there were no packets sent to the destination PC.

2.3 Subnet external IP Destination

For this second part of the laboratory, we moved on to PING-commands where the destination address was located in another subnet. Both subnets were connected by a router that assigned a range of addresses to the computers inside each subnet. Each computer inside one of these subnets was connected to a switch that had a connection to the router and the router provided a host IP-address for both subnets. Figure 2.5 shows all involved network node and their IP-addresses.

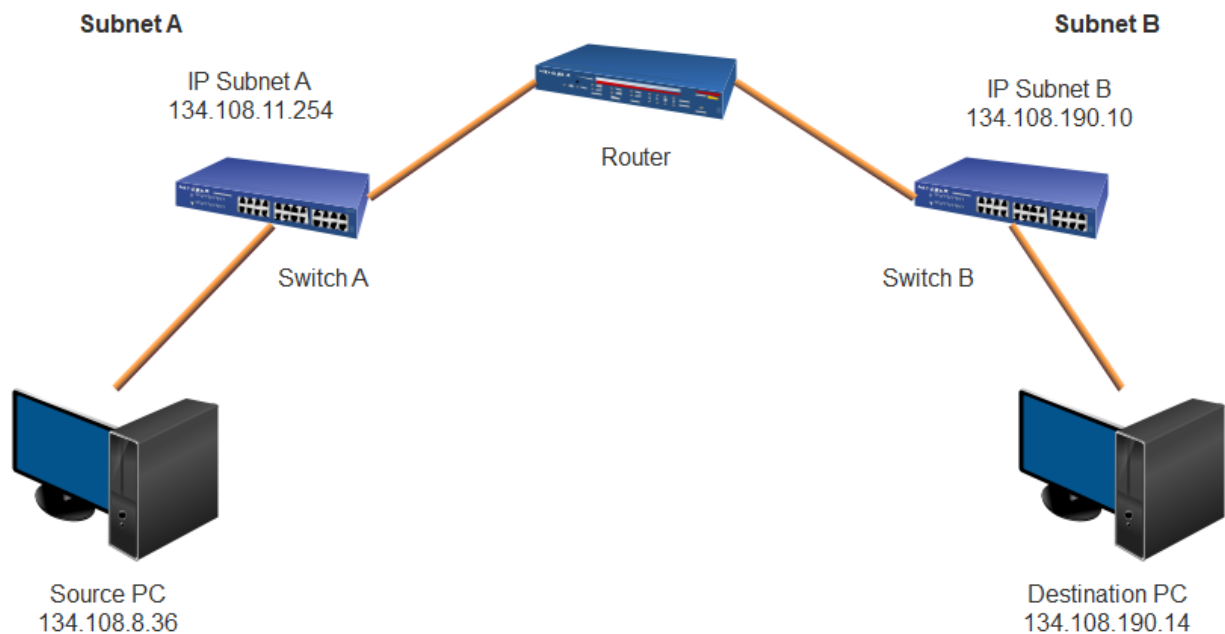


Figure 2.5: Two subnets in the network lab

2.3.1 d) Basic PING command with destination in another subnet

For this exercise the following PING-Command was used:

```
ping -n 1 -i 2 -r 4 134.108.190.10
```

The parameter **-r** activates the recoding of the route and sets the maximal number of records. **-i** indicates the 'Time to Live' in the IP-header (s. Chapter 2) and is basically nothing more than a hop-count that decrements, when the packet passes a network node (PCs or Routers in this case). When 'Time to Live' reaches zero, the packet will be abandoned. Figure 2.6 shows the output of the console command:

```
C:\Users\rn-labor>ping -n 1 -i 2 -r 4 134.108.190.10
Ping wird ausgeführt für 134.108.190.10 mit 32 Bytes Daten:
Antwort von 134.108.190.10: Bytes=32 Zeit<1ms TTL=63
Route: 134.108.190.14 ->
        134.108.190.10 ->
        134.108.190.10 ->
        134.108.11.254
Ping-Statistik für 134.108.190.10:
Pakete: Gesendet = 1, Empfangen = 1, Verloren = 0
        (0% Verlust),
Ca. Zeitangaben in Millisek.:
        Minimum = 0ms, Maximum = 0ms, Mittelwert = 0ms
```

Figure 2.6: PING Command with Destination in another subnet

The output shows the recorded route, the reply packet from the destination PC took through the network. The sent packets are shown in the following listing:

No.	Time	Source	Destination	Protocol	Length	DestPort	Info
				Delta Time			
2	49 0.000000	134.108.8.37	134.108.190.10	ICMP	94		Echo (ping) request id=0 x0001, seq=37/9472, ttl=2 (reply in 50) 0.000000
4	Frame 49: 94 bytes on wire (752 bits), 94 bytes captured (752 bits) on interface 0						
	Interface id: 0 (\\Device\\NPF_{55902047-E973-4FFC-B9C0-B0FAC2DA73AF})						
6	Interface name: \\Device\\NPF_{55902047-E973-4FFC-B9C0-B0FAC2DA73AF}						
	Encapsulation type: Ethernet (1)						
8	Arrival Time: Nov 17, 2017 10:21:22.503562000 Mitteleuropäische Zeit						
	[Time shift for this packet: 0.000000000 seconds]						
10	Epoch Time: 1510910482.503562000 seconds						
	[Time delta from previous captured frame: 0.187068000 seconds]						
12	[Time delta from previous displayed frame: 0.000000000 seconds]						
	[Time since reference or first frame: 2.480985000 seconds]						
14	Frame Number: 49						
	Frame Length: 94 bytes (752 bits)						
16	Capture Length: 94 bytes (752 bits)						
	[Frame is marked: True]						
18	[Frame is ignored: False]						
	[Protocols in frame: eth:ethertype:ip:icmp:data]						
20	[Coloring Rule Name: ICMP]						
	[Coloring Rule String: icmp || icmpv6]						
22	Ethernet II, Src: 90:b1:1c:88:97:76, Dst: 00:23:04:52:1c:00						
	Destination: 00:23:04:52:1c:00						
24	Address: 00:23:04:52:1c:00						
	.... 0. = LG bit: Globally unique address (factory default)						
26	.... 0 = IG bit: Individual address (unicast)						
	Source: 90:b1:1c:88:97:76						
28	Address: 90:b1:1c:88:97:76						
	.... 0. = LG bit: Globally unique address (factory default)						
30	.... 0 = IG bit: Individual address (unicast)						
	Type: IPv4 (0x0800)						
32	Internet Protocol Version 4, Src: 134.108.8.37, Dst: 134.108.190.10						
	0100 = Version: 4						
34	.... 1010 = Header Length: 40 bytes (10)						
	Differentiated Services Field: 0x00 (DSCP: CS0, ECN: Not-ECT)						
36	0000 00.. = Differentiated Services Codepoint: Default (0)						
	.... 00 = Explicit Congestion Notification: Not ECN-Capable Transport (0)						
38	Total Length: 80						
	Identification: 0x42d5 (17109)						
40	Flags: 0x00						
	0... = Reserved bit: Not set						
42	.0.. = Don't fragment: Not set						
	..0. = More fragments: Not set						
44	Fragment offset: 0						

```

Time to live: 2
46 [Expert Info (Note/Sequence): "Time To Live" only 2]
    ["Time To Live" only 2]
48 [Severity level: Note]
    [Group: Sequence]
50 Protocol: ICMP (1)
    Header checksum: 0x0000 [validation disabled]
52 [Header checksum status: Unverified]
    Source: 134.108.8.37
54 Destination: 134.108.190.10
    [Source GeoIP: Unknown]
56 [Destination GeoIP: Unknown]
    Options: (20 bytes), Record Route
58     IP Option - Record Route (19 bytes)
        Type: 7
60         0... .... = Copy on fragmentation: No
            .00. .... = Class: Control (0)
62         ...0 0111 = Number: Record route (7)
            Length: 19
64             Pointer: 4
                Empty Route: 0.0.0.0 <- (next)
66                 Empty Route: 0.0.0.0
                    Empty Route: 0.0.0.0
68                     Empty Route: 0.0.0.0
        IP Option - End of Options List (EOL)
70         Type: 0
            0... .... = Copy on fragmentation: No
72             .00. .... = Class: Control (0)
                ...0 0000 = Number: End of Option List (EOL) (0)
74 Internet Control Message Protocol
    Type: 8 (Echo (ping) request)
76    Code: 0
    Checksum: 0x4d36 [correct]
78    [Checksum Status: Good]
    Identifier (BE): 1 (0x0001)
80    Identifier (LE): 256 (0x0100)
    Sequence number (BE): 37 (0x0025)
82    Sequence number (LE): 9472 (0x2500)
    [Response frame: 50]
84    Data (32 bytes)

86    0000 61 62 63 64 65 66 67 68 69 6a 6b 6c 6d 6e 6f 70 abcdefghijklmnop
    0010 71 72 73 74 75 76 77 61 62 63 64 65 66 67 68 69 qrstuvwabcdefghi
88    Data: 6162636465666768696a6b6c6d6e6f707172737475767761...
    Text: abcdefghijklmnopqrstuvwxyzabcdefghi
90    [Length: 32]

92 No.      Time      Source      Destination      Protocol Length DestPort Info
                                Delta Time

```

```

50 0.000692 134.108.190.10 134.108.8.37 ICMP 94 Echo (ping) reply id=0
    x0001, seq=37/9472, ttl=63 (request in 49) 0.000692
94
Frame 50: 94 bytes on wire (752 bits), 94 bytes captured (752 bits) on interface 0
96   Interface id: 0 (\\Device\\NPF_{55902047-E973-4FFC-B9C0-B0FAC2DA73AF})
      Interface name: \\Device\\NPF_{55902047-E973-4FFC-B9C0-B0FAC2DA73AF}
98   Encapsulation type: Ethernet (1)
      Arrival Time: Nov 17, 2017 10:21:22.504254000 Mitteleuropäische Zeit
100   [Time shift for this packet: 0.000000000 seconds]
      Epoch Time: 1510910482.504254000 seconds
102   [Time delta from previous captured frame: 0.000692000 seconds]
      [Time delta from previous displayed frame: 0.000692000 seconds]
104   [Time since reference or first frame: 2.481677000 seconds]
      Frame Number: 50
106   Frame Length: 94 bytes (752 bits)
      Capture Length: 94 bytes (752 bits)
108   [Frame is marked: True]
      [Frame is ignored: False]
110   [Protocols in frame: eth:ethertype:ip:icmp:data]
      [Coloring Rule Name: ICMP]
112   [Coloring Rule String: icmp || icmpv6]
Ethernet II, Src: 00:23:04:52:1c:00, Dst: 90:b1:1c:88:97:76
114   Destination: 90:b1:1c:88:97:76
      Address: 90:b1:1c:88:97:76
116   .... 0. .... = LG bit: Globally unique address (factory default)
      .... 0. .... = IG bit: Individual address (unicast)
118   Source: 00:23:04:52:1c:00
      Address: 00:23:04:52:1c:00
120   .... 0. .... = LG bit: Globally unique address (factory default)
      .... 0. .... = IG bit: Individual address (unicast)
122   Type: IPv4 (0x0800)
Internet Protocol Version 4, Src: 134.108.190.10, Dst: 134.108.8.37
124   0100 .... = Version: 4
      .... 1010 = Header Length: 40 bytes (10)
126   Differentiated Services Field: 0x00 (DSCP: CS0, ECN: Not-ECT)
      0000 00.. = Differentiated Services Codepoint: Default (0)
128   .... 00 = Explicit Congestion Notification: Not ECN-Capable Transport (0)
      Total Length: 80
130   Identification: 0x048f (1167)
      Flags: 0x00
132   0... .... = Reserved bit: Not set
      .0.. .... = Don't fragment: Not set
134   ..0. .... = More fragments: Not set
      Fragment offset: 0
136   Time to live: 63
      Protocol: ICMP (1)
138   Header checksum: 0xafa3 [validation disabled]
      [Header checksum status: Unverified]
140   Source: 134.108.190.10
      Destination: 134.108.8.37

```

```

142 [Source GeoIP: Unknown]
    [Destination GeoIP: Unknown]
144 Options: (20 bytes), Record Route
    IP Option - Record Route (19 bytes)
146     Type: 7
        0... .... = Copy on fragmentation: No
148     .00. .... = Class: Control (0)
        ...0 0111 = Number: Record route (7)
150     Length: 19
        Pointer: 20
152     Recorded Route: 134.108.190.14
        Recorded Route: 134.108.190.10
154     Recorded Route: 134.108.190.10
        Recorded Route: 134.108.11.254
156     IP Option - End of Options List (EOL)
        Type: 0
158     0... .... = Copy on fragmentation: No
        .00. .... = Class: Control (0)
160     ...0 0000 = Number: End of Option List (EOL) (0)
Internet Control Message Protocol
162     Type: 0 (Echo (ping) reply)
        Code: 0
164     Checksum: 0x5536 [correct]
        [Checksum Status: Good]
166     Identifier (BE): 1 (0x0001)
        Identifier (LE): 256 (0x0100)
168     Sequence number (BE): 37 (0x0025)
        Sequence number (LE): 9472 (0x2500)
170     [Request frame: 49]
        [Response time: 0.692 ms]
172     Data (32 bytes)

174 0000 61 62 63 64 65 66 67 68 69 6a 6b 6c 6d 6e 6f 70 abcdefghijklmnop
    0010 71 72 73 74 75 76 77 61 62 63 64 65 66 67 68 69 qrstuvwabcdefghi
176 Data: 6162636465666768696a6b6c6d6e6f707172737475767761...
    Text: abcdefghijklmnopqrstuvwxyzabcdefghi
178 [Length: 32]

```

Listing 2.3: Wireshark trace for PING command in another subnet

2.3.2 e) PING command with reduced 'time to live'

In this exercise the 'Time to Live' was reduced to 1 in the PING-Command:

```
ping -n 1 -i 1 -r 4 134.108.190.10
```

This causes a Time-To-Live-Exceeded error that was displayed in the console output:

```
C:\Users\rn-labor>ping -n 1 -i 1 -r 4 134.108.190.10

Ping wird ausgeführt für 134.108.190.10 mit 32 Bytes Daten:
Antwort von 134.108.11.254: Die Gültigkeitsdauer wurde bei der Übertragung überschritten.

Ping-Statistik für 134.108.190.10:
    Pakete: Gesendet = 1, Empfangen = 1, Verloren = 0
    (0% Verlust),
```

Figure 2.7: PING Command with reduced Time to Live

As the 'Time to Live' is reduced to 1, it cannot reach the destination PC. When bypassing the router, the TTL is decreased to zero. So the router will drop the packet and send the Time-To-Live-Exceeded error back to the source, while the destination PC never receives any traffic. The only packet sent is from the source to the router. This can be seen in the following Wireshark trace:

No.	Time	Source	Destination	Protocol	Length	DestPort	Info
				Delta Time			
2	37 0.000000	134.108.8.37	134.108.190.10	ICMP	94		Echo (ping) request id=0 x0001, seq=38/9728, ttl=1 (no response found!) 0.000000
4	Frame 37: 94 bytes on wire (752 bits), 94 bytes captured (752 bits) on interface 0						
	Interface id: 0 (\\Device\\NPF_{55902047-E973-4FFC-B9C0-B0FAC2DA73AF})						
6	Interface name: \\Device\\NPF_{55902047-E973-4FFC-B9C0-B0FAC2DA73AF}						
	Encapsulation type: Ethernet (1)						
8	Arrival Time: Nov 17, 2017 10:23:18.619066000 Mitteleuropäische Zeit						
	[Time shift for this packet: 0.000000000 seconds]						
10	Epoch Time: 1510910598.619066000 seconds						
	[Time delta from previous captured frame: 0.145036000 seconds]						
12	[Time delta from previous displayed frame: 0.000000000 seconds]						
	[Time since reference or first frame: 5.672194000 seconds]						
14	Frame Number: 37						
	Frame Length: 94 bytes (752 bits)						
16	Capture Length: 94 bytes (752 bits)						
	[Frame is marked: True]						
18	[Frame is ignored: False]						
	[Protocols in frame: eth:ethertype:ip:icmp:data]						
20	[Coloring Rule Name: ICMP]						
	[Coloring Rule String: icmp || icmpv6]						
22	Ethernet II, Src: 90:b1:1c:88:97:76, Dst: 00:23:04:52:1c:00						
	Destination: 00:23:04:52:1c:00						
24	Address: 00:23:04:52:1c:00						
	.... 0. = LG bit: Globally unique address (factory default)						
26	.... 0 = IG bit: Individual address (unicast)						
	Source: 90:b1:1c:88:97:76						
28	Address: 90:b1:1c:88:97:76						
	.... 0. = LG bit: Globally unique address (factory default)						

```

30      .... ..0 .... .. = IG bit: Individual address (unicast)
      Type: IPv4 (0x0800)
32 Internet Protocol Version 4, Src: 134.108.8.37, Dst: 134.108.190.10
      0100 .... = Version: 4
34      .... 1010 = Header Length: 40 bytes (10)
      Differentiated Services Field: 0x00 (DSCP: CS0, ECN: Not-ECT)
36      0000 00.. = Differentiated Services Codepoint: Default (0)
      .... ..00 = Explicit Congestion Notification: Not ECN-Capable Transport (0)
38      Total Length: 80
      Identification: 0x42d9 (17113)
40      Flags: 0x00
      0... .... = Reserved bit: Not set
42      .0.. .... = Don't fragment: Not set
      ..0. .... = More fragments: Not set
44      Fragment offset: 0
      Time to live: 1
46      [Expert Info (Note/Sequence): "Time To Live" only 1]
      ["Time To Live" only 1]
48      [Severity level: Note]
      [Group: Sequence]
50      Protocol: ICMP (1)
      Header checksum: 0x0000 [validation disabled]
52      [Header checksum status: Unverified]
      Source: 134.108.8.37
54      Destination: 134.108.190.10
      [Source GeoIP: Unknown]
56      [Destination GeoIP: Unknown]
      Options: (20 bytes), Record Route
58      IP Option - Record Route (19 bytes)
          Type: 7
60          0... .... = Copy on fragmentation: No
          .00. .... = Class: Control (0)
62          ...0 0111 = Number: Record route (7)
          Length: 19
64          Pointer: 4
              Empty Route: 0.0.0.0 <- (next)
66              Empty Route: 0.0.0.0
              Empty Route: 0.0.0.0
68              Empty Route: 0.0.0.0
      IP Option - End of Options List (EOL)
70      Type: 0
          0... .... = Copy on fragmentation: No
72          .00. .... = Class: Control (0)
          ...0 0000 = Number: End of Option List (EOL) (0)
74 Internet Control Message Protocol
      Type: 8 (Echo (ping) request)
76      Code: 0
      Checksum: 0x4d35 [correct]
78      [Checksum Status: Good]
      Identifier (BE): 1 (0x0001)

```

```

80 Identifier (LE): 256 (0x0100)
Sequence number (BE): 38 (0x0026)
82 Sequence number (LE): 9728 (0x2600)
[No response seen]
84 [Expert Info (Warning/Sequence): No response seen to ICMP request]
[No response seen to ICMP request]
86 [Severity level: Warning]
[Group: Sequence]
88 Data (32 bytes)

90 0000 61 62 63 64 65 66 67 68 69 6a 6b 6c 6d 6e 6f 70 abcdefghijklmnop
0010 71 72 73 74 75 76 77 61 62 63 64 65 66 67 68 69 qrstuvwabcdefghi
92 Data: 6162636465666768696a6b6c6d6e6f707172737475767761...
Text: abcdefghijklmnopqrstuvwxyzabcdefghi
94 [Length: 32]

```

Listing 2.4: Wireshark trace for PING command with reduced TTL

2.3.3 f) PING command with timestamps

In this exercise the 'timestamp' option was used in the PING-Command:

```
ping -n 1 -i 2 -s 4 134.108.190.10
```

The timestamp option has the effect that a timestamp which represents the amount of time from midnight to the exact moment, the packet bypasses a network node, is recorded in milliseconds:

```

C:\Users\rn-labor>ping -n 1 -i 2 -s 4 134.108.190.10

Ping wird ausgeführt für 134.108.190.10 mit 32 Bytes Daten:
Antwort von 134.108.190.10: Bytes=32 Zeit<1ms TTL=63
    Zeitstempel: 134.108.190.14 : 34336822 ->
                  134.108.190.10 : 34336823 ->
                  134.108.190.10 : 34336823 ->
                  134.108.11.254 : 34336823

Ping-Statistik für 134.108.190.10:
    Pakete: Gesendet = 1, Empfangen = 1, Verloren = 0
    (0% Verlust),
    Ca. Zeitangaben in Millisek.:
    Minimum = 0ms, Maximum = 0ms, Mittelwert = 0ms

```

Figure 2.8: PING Command with timestamp option

The time difference between the sending from the destination PC and the bypassing of the router is only 1 ms as seen in Figure 2.8. The Options Field in the IP-header contains the timestamps as seen in the following listing: ,

```

2  No.      Time      Source      Destination      Protocol Length DestPort Info
                                     Delta Time
51 0.000778 134.108.190.10 134.108.8.37    ICMP      110          Echo (ping) reply id=0
    x0001, seq=43/11008, ttl=63 (request in 50) 0.000778
4
6  Frame 51: 110 bytes on wire (880 bits), 110 bytes captured (880 bits) on interface 0
    Interface id: 0 (\\Device\\NPF_{55902047-E973-4FFC-B9C0-B0FAC2DA73AF})
    Interface name: \\Device\\NPF_{55902047-E973-4FFC-B9C0-B0FAC2DA73AF}
8  Encapsulation type: Ethernet (1)
    Arrival Time: Nov 17, 2017 10:32:16.698574000 Mitteleuropäische Zeit
10 [Time shift for this packet: 0.000000000 seconds]
    Epoch Time: 1510911136.698574000 seconds
12 [Time delta from previous captured frame: 0.000778000 seconds]
    [Time delta from previous displayed frame: 0.000778000 seconds]
14 [Time since reference or first frame: 3.015108000 seconds]
    Frame Number: 51
16 Frame Length: 110 bytes (880 bits)
    Capture Length: 110 bytes (880 bits)
18 [Frame is marked: True]
    [Frame is ignored: False]
20 [Protocols in frame: eth:ethertype:ip:icmp:data]
    [Coloring Rule Name: ICMP]
22 [Coloring Rule String: icmp || icmpv6]
    Ethernet II, Src: 00:23:04:52:1c:00, Dst: 90:b1:1c:88:97:76
24 Destination: 90:b1:1c:88:97:76
    Address: 90:b1:1c:88:97:76
26 .... ..0. .... = LG bit: Globally unique address (factory default)
    .... ..0. .... = IG bit: Individual address (unicast)
28 Source: 00:23:04:52:1c:00
    Address: 00:23:04:52:1c:00
30 .... ..0. .... = LG bit: Globally unique address (factory default)
    .... ..0. .... = IG bit: Individual address (unicast)
32 Type: IPv4 (0x0800)
Internet Protocol Version 4, Src: 134.108.190.10, Dst: 134.108.8.37
34 0100 .... = Version: 4
    .... 1110 = Header Length: 56 bytes (14)
36 Differentiated Services Field: 0x00 (DSCP: CS0, ECN: Not-ECT)
    0000 00.. = Differentiated Services Codepoint: Default (0)
38 .... ..00 = Explicit Congestion Notification: Not ECN-Capable Transport (0)
    Total Length: 96
40 Identification: 0x0490 (1168)
    Flags: 0x00
42 0... .... = Reserved bit: Not set
    .0.. .... = Don't fragment: Not set
44 ..0. .... = More fragments: Not set
    Fragment offset: 0
46 Time to live: 63
    Protocol: ICMP (1)

```



```

48   Header checksum: 0x0901 [validation disabled]
    [Header checksum status: Unverified]
50   Source: 134.108.190.10
    Destination: 134.108.8.37
52   [Source GeoIP: Unknown]
    [Destination GeoIP: Unknown]
54   Options: (36 bytes), Time Stamp
    IP Option - Time Stamp (36 bytes)
56     Type: 68
        0... .... = Copy on fragmentation: No
58     .10. .... = Class: Debugging and measurement (2)
        ...0 0100 = Number: Time stamp (4)
60     Length: 36
        Pointer: 37
62     0000 .... = Overflow: 0
        .... 0001 = Flag: Time stamp and address (0x1)
64     Address: 134.108.190.14
        Time stamp: 34336822
66     Address: 134.108.190.10
        Time stamp: 34336823
68     Address: 134.108.190.10
        Time stamp: 34336823
70     Address: 134.108.11.254
        Time stamp: 34336823
72 Internet Control Message Protocol
    Type: 0 (Echo (ping) reply)
74    Code: 0
    Checksum: 0x5530 [correct]
76    [Checksum Status: Good]
    Identifier (BE): 1 (0x0001)
78    Identifier (LE): 256 (0x0100)
    Sequence number (BE): 43 (0x002b)
80    Sequence number (LE): 11008 (0x2b00)
    [Request frame: 50]
82    [Response time: 0.778 ms]
Data (32 bytes)
84
    0000 61 62 63 64 65 66 67 68 69 6a 6b 6c 6d 6e 6f 70 abcdefghijklmnop
86    0010 71 72 73 74 75 76 77 61 62 63 64 65 66 67 68 69 qrstuvwabcdefghi
    Data: 6162636465666768696a6b6c6d6e6f707172737475767761...
88    Text: abcdefghijklmnopqrstuvwxyzabcdefghi
    [Length: 32]

```

Listing 2.5: Wireshark trace for PING command with timestamps

2.4 ARP analysis

2.4.1 a) Deleting the ARP cache

2.4.2 b) Shutting down one PC

2.4.3 c) Reconnect after Reboot

2.5 IP multicast addressing

3 TCP analysis

3.1 Traffic generator handling

3.2 Simple TCP Communication

3.2.1 Connection establishment

3.2.2 Data transfer

3.2.3 Connection release

3.3 TCP flow control

3.4 TCP transmission error recovery/abort

3.5 TCP protocol errors (synchronization errors)

4 IPv6/ICMPv6 analysis

4.1 Node configuration

4.1.1 IPv4 and IPv6 configuration

4.1.2 interfaces for IPv6

4.2 PING commands

4.2.1 a) Basic ICMPv6 PING command

4.2.2 b) ICMPv6 PING command with large data package

4.2.3 c) Rebooting PC

4.2.4 d) Enforcing Neighbor discovery

4.2.5 e) ICMPv6 PING command with destination in another subnet

4.2.6 f) PING to a remote tunnel end

5 Conclusion

Bibliography

- [Bec04] Kent Beck. *Test-Driven development by Example*. Pearson, 2004. ISBN: 8131715957.
- [WMV03] Laurie Williams, E. Michael Maximilien, and Mladen Vouk. “Test-Driven Development as a Defect-Reduction Practice”. In: *14th IEEE International Symposium on Software Reliability Engineering ISSRE 2003*. Denver, Colorado: IEEE, 2003. URL: <http://ieeexplore.ieee.org/document/1251029/> (visited on 10/01/2016).