Problem 1

Comparing the received data with the headers of IP and Layer 4 protocols gives the following interpretation. The structure is filled in with Hexadecimal numbers (or binay in some case) and if needed translated to decimal below the cell. To right are the relevant data explained. From the IP protocol it is seen that the UDP is used on layer 4.

IP

	Byte 1	Byte 2	Byte 3	Byte 4	
Row 1	4 | 5	00	04CC		IPv4, 5x4=20B Header 1228 total length of datagram
			1228		
Row 2	9CBB		010 | 00000	00	D=1 => Do not fragment
Row 3	05	11	4BA0		TTL=5, 17=> UDP at L4 Checksum=4BA0
		17			
Row 4	C0	A8	05	4E	Source address: 192.168.5.78
	192	168	5	78	
Row 5	82	EB	3F	E4	Destination address: 130.235.63.228
	130	235	63	228	

UDP

	Byte 1	Byte 2	Byte 3	Byte 4	
Row 1	1AE1		1AE5		Source port:6881 Destination port: 6885
	6881		6885		
Row 2	04B8		B152		Length: 1208
	1208				

From this we get the following answers.

(a)
- Protocols: L3 IPv4 and L4 UDP
- Payload: L3 1208 Bytes and L4 1200 Bytes
- Addressing as sockets
  Source: 192.168.5.78:6881
  Destination: 130.235.3.228:6885

(b) From a search (e.g. UDP port 6881) it seems the ports are not offixcially reserved. However bitTorrent uses 6881-6887 for both UDP and TCP. So, it is likely a file sharing application.

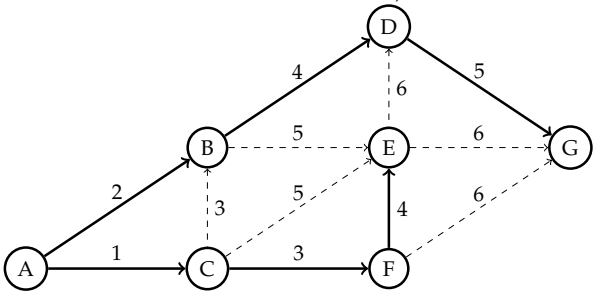
(c) Adding the four digit hex numbers gives the sum 2FFFD. To get the check sum result wrap in four digit numbers and add, FFFD+2=FFFF, and bitwise inversion to get 0000. hence, the IP header is received correct.

Note: To convert between hex and decimal the Matlab commands dec2hex and hex2dec can be used. So the sum can be derived by

```
>> IP=['4500'; '04CC'; '9CBB'; '4000'; '0511'; '4BA0'; 'C0A8'; '054E'; '82EB'; '3FE4'];
>> dec2hex(sum(hex2dec(IP)))
ans =
2FFFD
>>
```

Problem 2

(a) The tree and routing table from node A becomes (selected edges in bold and discarded dashed. Edges are marked with comulative cost.):



Destination	Next hop	cost
B	B	2
C	C	1
D	B	4
E	C	4
F	C	3
G	B	5

(b) The initial tables at node C and F are
Initial C

Dest.	Next hop	cost
A	A	1
B	B	2
E	E	4
F	F	2

Initial C

Dest.	Next hop	cost
C	C	2
E	E	1
G	G	3

After updating the table at C with data from F:

Dest.	Next hop	cost
A	A	1
B	B	2
E	F	3
F	F	2
G	F	5

Problem 3

(a) Let T be the round-trip time (message+ACK). Then $E[T] = T_{t1} + T_{t2} + 2T_p$ and the utilisation is $T_{t1}/E[T]$.

(b) Expected number of retransmissions are

$$E[\#\text{ Retrans}] = \sum_{i=0}^{\infty} i(1-q)^i q = (1-q)q \sum_{i=0}^{\infty} i(1-q)^{i-1} = (1-q)q\frac{1}{q^2} = \frac{1-q}{q}$$

(c) The probability for correct transmission cen be derived from the (independent) probablities of correct message and correct ACK as $q = (1-p_1)(1-p_2)$. The total time to delivey, T_d, can now be derived as

$$E[T_d] = E[T] + \sum_{i=1}^{\infty} T_o i(1-q)^i q = E[T] + \frac{1-q}{q}T_o = T_{t1} + T_{t2} + 2T_p + \frac{1-q}{q}T_o$$

Inserting the numbers in the problem gives $E[T_d] = 1 + 1 + 0.2 + \frac{1-0.81}{0.81} = 3.37$.

Problem 4

(a) There are seven networks:

Address	Description
139.16.1.0	Left of R1
100.5.10.0	Between R2 and R4
100.5.10.64	Between R1 and R2
100.5.10.128	Between R3 and R4
100.5.10.192	Between R1 and R3
104.1.10.0	Right of R4
130.235.0.0	Below R2 (LU address space)

(b) Assume R1 is a DHCP server. Then when Comp 2 connects to the network it will ask for an IP address.

L2		L3			
Source	**Dest**	**Source**	**Dest**	**Message**	**Comment**
00:46:22:a1:84:e2	ff.ff.ff.ff.ff.ff	0.0.0.0	255.255.255.255	DHCPDISCOVER	Comp2 to all
00:59:a4:ff:01:23	ff.ff.ff.ff.ff.ff	139.16.1.1	255.255.255.255	DHCPOFFER IP: 139.16.1.12 LT:1440 DNS: 130.235.63.228 defGW: 139.16.1.1 NetwMask:255.255.255.0	R1 to Comp2
00:46:22:a1:84:e2	ff.ff.ff.ff.ff.ff	0.0.0.0	255.255.255.255	DHCPREQUEST IP: 139.16.1.12 LT:1440 DNS: 130.235.63.228 defGW: 139.16.1.1 NetwMask:255.255.255.0	Comp2 to all
00:59:a4:ff:01:23	ff.ff.ff.ff.ff.ff	139.16.1.1	255.255.255.255	DHCPACK	R1 to Comp2

After this Comp2 has accepted the IP address 139.16.1.12. It also knows the DNS server, the default gateway, network mask and the leas time (here 24 hours).

(c) To call www.web.com Comp2 first needs the IP address, so it has to call the DNS server. The DNS connection is through UDP and then when calling the web server it has to set up a TCP connection (and

disconnect it afterwards). It turns out that there is an image to fetched at another server and again a DNS request and a TCP connection is used. The layer 2 addressing changes between the networks, and the number of packets bekomes quite extensive. Still, it is a manageble list since most parts are unchanged. In Figure 4.1 the packets for retreiving the file index.html is shown. In the first rows the complete packets are shown, while in the continuation only the changes are shown. In Figure 4.2 the packets for retreiving the image is shown. In the tables the ports 1444 and 1500 used for DNS can be any port above 1024.

Addressing						
L2		L3		L4		
Source	Dest	Source	Dest	Source	Dest	Description
00:46:22:a1:84:e2	00:59:a4:ff:01:23	139.16.1.12	130.235.63.228	1444	53	C2->DNS: www.web.com?
00:23:45:11:9a:b8	00:a5:22:74:11:e2	139.16.1.13	130.235.63.229	1444	53	C2->DNS: www.web.com?
00:91:de:2e:58:a2	00:2e:33:82:f2:0a	139.16.1.14	130.235.63.230	1444	53	C2->DNS: www.web.com?
00:2e:33:82:f2:0a	00:91:de:2e:58:a2	130.235.63.230	139.16.1.14	53	1444	DNS-C2:104.1.10.137
00:a5:22:74:11:e2	00:23.45:11:9a:b8	130.235.63.231	139.16.1.15	53	1444	DNS-C2:104.1.10.138
00:59:a4:ff:01:23	00:46:22:a1:84:e2	130.235.63.232	139.16.1.16	53	1444	DNS-C2:104.1.10.139
00:46:22:a1:84:e2	00:59:a4:ff:01:23	139.16.1.12	104.1.10.138	80	8080	TCP: SYN (Establish connection)
00:23:45:f1:9a:b8	00:a5:22:74:f1:e2					
00:33:00:00:28:1a	00:28:45:b5:2d:ef					
00:10:30:40:2f:a1	00:14:45:72:fe:a8					
00:14:45:72:fe:a8	00:10:30:40:2f:a1	104.1.10.138	139.16.1.12	8080	80	TCP:SYN ACK
00:28:45:b5:2d:ef	00:33:00:00:28:1a					
00:a5:22:74:f1:e2	00:23:45:f1:9a:b8					
00:59:a4:ff:01:23	00:46:22:a1:84:e2					
00:46:22:a1:84:e2	00:59:a4:ff:01:23	139.16.1.12	104.1.10.138	80	8080	TCP: ACK
00:23:45:f1:9a:b8	00:a5:22:74:f1:e2					
00:33:00:00:28:1a	00:28:45:b5:2d:ef					
00:10:30:40:2f:a1	00:14:45:72:fe:a8					
00:46:22:a1:84:e2	00:59:a4:ff:01:23	139.16.1.12	104.1.10.138	80	8080	HTTP: GET file/index.html
00:23:45:f1:9a:b8	00:a5:22:74:f1:e2					
00:33:00:00:28:1a	00:28:45:b5:2d:ef					
00:10:30:40:2f:a1	00:14:45:72:fe:a8					
00:14:45:72:fe:a8	00:10:30:40:2f:a1	104.1.10.138	139.16.1.12	8080	80	HTTP: Return file
00:28:45:b5:2d:ef	00:33:00:00:28:1a					
00:a5:22:74:f1:e2	00:23:45:f1:9a:b8					
00:59:a4:ff:01:23	00:46:22:a1:84:e2					
00:46:22:a1:84:e2	00:59:a4:ff:01:23	139.16.1.12	104.1.10.138	80	8080	TCP: ACK
00:23:45:f1:9a:b8	00:a5:22:74:f1:e2					
00:33:00:00:28:1a	00:28:45:b5:2d:ef					
00:10:30:40:2f:a1	00:14:45:72:fe:a8					
00:46:22:a1:84:e2	00:59:a4:ff:01:23	139.16.1.12	104.1.10.138	80	8080	TCP: FIN (Closing connection)
00:23:45:f1:9a:b8	00:a5:22:74:f1:e2					
00:33:00:00:28:1a	00:28:45:b5:2d:ef					
00:10:30:40:2f:a1	00:14:45:72:fe:a8					
00:14:45:72:fe:a8	00:10:30:40:2f:a1	104.1.10.138	139.16.1.12	8080	80	TCP: FIN ACK
00:28:45:b5:2d:ef	00:33:00:00:28:1a					
00:a5:22:74:f1:e2	00:23:45:f1:9a:b8					
00:59:a4:ff:01:23	00:46:22:a1:84:e2					
00:46:22:a1:84:e2	00:59:a4:ff:01:23	139.16.1.12	104.1.10.138	80	8080	TCP: ACK
00:23:45:f1:9a:b8	00:a5:22:74:f1:e2					
00:33:00:00:28:1a	00:28:45:b5:2d:ef					
00:10:30:40:2f:a1	00:14:45:72:fe:a8					

Figure 4.1: Packets through the network for retrieving the file index.html

Addressing						
L2		L3		L4		
Source	Dest	Source	Dest	Source	Dest	Description
00:46:22:a1:84:e2	00:59:a4:ff:01:23	139.16.1.12	130.235.63.228	53	53	C2->DNS: www.imgstore.net?
00:23:45:11:9a:b8	00:a5:22:74:11:e2					
00:91:de:2e:58:a2	00:2e:33:82:f2:0a					
00:2e:33:82:f2:0a	00:91:de:2e:58:a2	130.235.63.230	139.16.1.14	53	53	DNS-C2:130.235.201.2
00:a5:22:74:11:e2	00:23.45:11:9a:b8					
00:59:a4:ff:01:23	00:46:22:a1:84:e2					
00:46:22:a1:84:e2	00:59:a4:ff:01:23	139.16.1.12	130.235.201.2	80	80	TCP: SYN (Establish connection)
00:23:45:f1:9a:b8	00:a5:22:74:f1:e2					
00:91:de:2e:58:a2	00:2e:33:82:f2:0a					
00:2e:33:82:f2:0a	00:91:de:2e:58:a2	130.235.201.2	139.16.1.12	80	80	TCP:SYN ACK
00:a5:22:74:f1:e2	00:23:45:f1:9a:b8					
00:59:a4:ff:01:23	00:46:22:a1:84:e2					
00:46:22:a1:84:e2	00:59:a4:ff:01:23	139.16.1.12	130.235.201.2	80	80	TCP: ACK
00:23:45:f1:9a:b8	00:a5:22:74:f1:e2					
00:91:de:2e:58:a2	00:2e:33:82:f2:0a					
00:46:22:a1:84:e2	00:59:a4:ff:01:23	139.16.1.12	130.235.201.2	80	80	HTTP: GET image/star.jpg
00:23:45:f1:9a:b8	00:a5:22:74:f1:e2					
00:91:de:2e:58:a2	00:2e:33:82:f2:0a					
00:2e:33:82:f2:0a	00:91:de:2e:58:a2	130.235.201.2	139.16.1.12	80	80	HTTP: Return image
00:a5:22:74:f1:e2	00:23:45:f1:9a:b8					
00:59:a4:ff:01:23	00:46:22:a1:84:e2					
00:46:22:a1:84:e2	00:59:a4:ff:01:23	139.16.1.12	130.235.201.2	80	80	TCP: ACK
00:23:45:f1:9a:b8	00:a5:22:74:f1:e2					
00:91:de:2e:58:a2	00:2e:33:82:f2:0a					
00:46:22:a1:84:e2	00:59:a4:ff:01:23	139.16.1.12	130.235.201.2	80	80	TCP: FIN (Closing connection)
00:23:45:f1:9a:b8	00:a5:22:74:f1:e2					
00:91:de:2e:58:a2	00:2e:33:82:f2:0a					
00:2e:33:82:f2:0a	00:91:de:2e:58:a2	130.235.201.2	139.16.1.12	80	80	TCP: FIN ACK
00:a5:22:74:f1:e2	00:23:45:f1:9a:b8					
00:59:a4:ff:01:23	00:46:22:a1:84:e2					
00:46:22:a1:84:e2	00:59:a4:ff:01:23	139.16.1.12	130.235.201.2	80	80	TCP: ACK
00:23:45:f1:9a:b8	00:a5:22:74:f1:e2					
00:91:de:2e:58:a2	00:2e:33:82:f2:0a					

Figure 4.2: Packets through the network for retrieving the image star.jpg

Problem 5

(a) For all bandwidths:

T_s [ms]				R_s [kHz]			
frame	sub frame	slot	OFDM	frame	sub frame	slot	OFDM
10	1	0.5	0.0714	0.1	1	2	14

(b) With $2 \times 15 = 30$ bit/complex sample we get the following table. This is only the one-way direction and for one LTE antenna the total bit rate must be doubled.

W [MHz]	1.4	3	5	10	15	20
FFTsize	128	256	512	1024	1536	2048
CPa	10	20	40	80	120	160
CPb	9	18	36	72	108	144
Sampl/slot (7FFTsize + 6CPb + CPb)	960	1920	3840	7680	11520	15360
F_s [MHz, i.e. S/s] ($S/slot \times 2k$)	1.92	3.84	7.68	15.36	23.04	30.72
R_b [Mb/s] ($F_s \times 30$)	57.6	115.2	230.4	460.8	691.2	921.6
T_b [ns] ($1/R_b$)	17.3	8.68	4.34	2.17	1.45	1.09

(c) With 14 000 OFDM frames per second and 6 b/sample we get the following table.

W [MHz]	1.4	3	5	10	15	20
R_b [Mb/s] data ($DS \times 6 \times 14k$)	6.05	15.1	25.2	50.4	75.6	100.8
Expansion	9.5	7.6	9.1	9.1	9.1	9.1

(In many network architecture discussions today, the BBU is centralized in the network while the RU is located further out. Then it is assumed that CPRI is used for transmitting the radio signal over the network, meaning an extensive increase in traffic since each RU serves several LTE antennas. It should also be considered that the next generation LTE, LTE-A, uses a bandwidth of 100 MHz, containing five 20 MHz LTE channels.)