

Homework 1  
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Remove all highlights before typing your answer.

## 1 Signal Encoding

- (a) (3) Lower frequencies have a much longer reach so it makes sense to regulate them so they can be used across countries and among different applications. Higher frequencies have a much lower reach making them less usable and thus less important to regulate.
- (8) Problems of signal propagation included, attenuation, diffraction, scattering, refraction and reflection. Since signal propagation is unpredictable it will not always travel in a straight line. For example, the transmitter and receiver could be moving, or the signal could degrade over distance or terrain. Reflection is useful in propagation because there is almost never a clear line of sight between the source and destination. Reflection is harmful because it is the main reason for multi-path propagation causing ISI.
- (9) ISI can be mitigated by large guard times between symbols, calculation of the strongest transmission paths and having the receiver use those paths, and lower data rates. ISI is less problematic with higher carrier frequencies. The higher the symbol rate the shorter the transmission time so ISI effects become worse. The more movement the more recalculation of the path is needed, creating more problems for ISI. In a TDM scheme ISI sets the number of users of a channel, and the maximum data rate allowed for each user.
- (12) For a recieved signal the point in the phase diagram is compared to the surrounding points. The received point is corrected to the closest allowed point. Adding more and more points increases the risk to correct a received point incorrectly if the average distance to the correct point becomes more than half the distance between allowed points.
- (b)
- -9.03 dBm
  - -6.2 dBm
  - -3.1 dBm
  - 0 dBm
  - 3.01 dBm
  - 6.02 dBm
  - 9.03 dBm

The conversion follows a logarithmic function specifically  $P(dBm) = 10 * \log(P(W)) + 30$

- (c)  $S(t) = (1.0 + 0.1 \cos 5t) \cos 100t$ :  
 $= \cos 100t + 0.1 \cos 100t \cos 5t$   
 $= \cos 100t + \frac{0.1}{2} (\cos (100 + 5)t + \cos (100 - 5)t)$   
 $= \cos 100t + 0.05 \cos (100 + 5)t + 0.05 \cos (100 - 5)t$

$$\begin{aligned}
&= \cos 100t + 0.05 \cos 105t + 0.05 \cos 95t \\
&= \cos 2\frac{50}{\pi}t + 0.05 \cos 2\frac{105}{2\pi}t + 0.05 \cos 2\frac{95}{2\pi}t \\
&= \sin 2\frac{50}{\pi}t + 0.05 \sin 2\frac{105}{2\pi}t + 0.05 \sin 2\frac{95}{2\pi}t
\end{aligned}$$

**Answer:**

$$\begin{aligned}
\sin 2\frac{50}{\pi}t: & \text{Amplitude} = 1, \text{ frequency} = \frac{50}{\pi}, \text{ phase} = \frac{\pi}{2} \\
0.05 \sin 2\frac{105}{2\pi}t: & \text{Amplitude} = 0.05, \text{ frequency} = \frac{105}{2\pi}, \text{ phase} = \frac{\pi}{2} \\
0.05 \sin 2\frac{95}{2\pi}t: & \text{Amplitude} = 0.05, \text{ frequency} = \frac{95}{2\pi}, \text{ phase} = \frac{\pi}{2}
\end{aligned}$$

- (d) Binary values are represented by two different amplitudes of carrier frequencies in ASK. Vulnerability to sudden gain changes and inefficiency at handling noise are the primary limitations of this approach.

(e)

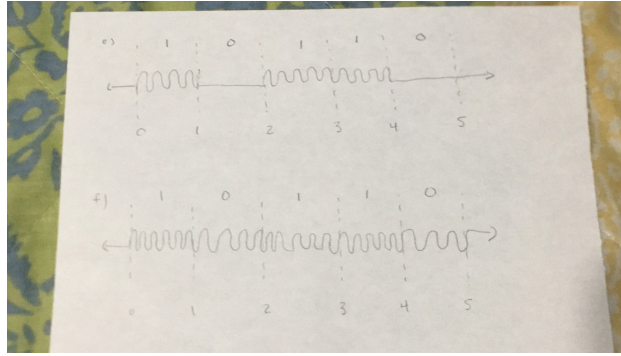


Figure 1: part (e) and (f)

(f)

- (g) For ASK and FSK a signal to noise ratio of  $13.5dB$  is needed for a bandwidth efficiency of 1.0

## 2 Channel Capacity, Models

- (a)  $PL(d_0)$  is the frequency dependent component and  $\alpha$  is the path loss gradient. The value of  $\alpha$  determines how quickly the received signal strength (RSS) falls with distance so the formula  $PL(d) = PL(d_0) + 10 * \alpha * \log_{10}d/d_0$  makes sense.

- (b) • For  $d = 2d_0$ :

$$PL(d) = 40 + 10 * 2.4 * \log_{10}(2d_0/d_0) = 40 + 10 * 2.4 * 0.0301 = 47.2247$$

- For  $d = 4d_0$ :

$$PL(d) = 40 + 10 * 2.4 * \log_{10}(4d_0/d_0) = 40 + 10 * 2.4 * 0.0602 = 54.4494$$

- Path loss = 64dB:

Since  $40 + 10 * 2.4 = 63$  and  $\log_{10}10 = 1$  **then**  $d = 10d_0$

- (c)    • A  $\rightarrow$  B:

$$10 * \log_{10}10^{-3} - P_{Rx}(dB) = 20dB + (10 * 3)\log_{10}30 - 30 - P_{Rx}(dB) = 64.3dB$$

**Answer:**  $P_{Rx}(dB) \text{ a} + \text{b} = -94.3dB$

- B  $\rightarrow$  C:

$$-94.3dB - P/a + c = 20dB + 30 * \log_{10}20 = 59.03$$

**Answer:**  $P \text{ a}+c(dB) = -153.33dB$

- (d) Using the equation:  $C = B\log_2(1 + SNR)$

$$20 * 10^6 = 3 * 10^6 * \log_2(1 + SNR)$$

$$\log_2(1 + SNR) = 6.67$$

$$1 + SNR = 2^{6.67}$$

$$1 + SNR = 102$$

**Answer:**  $SNR = 101$

### 3 Spread Spectrum and OFDM

- (a) A spread spectrum system is robust against interference making it beneficial in providing security. It also serves as the basis for CDMA technology. Spreading is achieved through frequency hopping. Guard spaces are replaced by the orthogonality of the hopping patterns. Multi-path propagation can be benefited by DSSS systems through recombination which results in a stronger signal.
- (b) It has orthogonality. Which means the frequency spacing is  $\frac{1}{T}$ , and if the bit time is T then the base frequency should be a multiple of  $\frac{1}{T}$
- (c) Main strengths of OFDM include, efficient use of the spectrum through overlap, resistance to frequency selective fading, and the elimination of ISI and IFI through the use of a cyclic prefix.
- (d) In OFDM the users are allocated only on the time domain. On the other hand OFDMA allows users to be allocated both time and frequency. Thus in OFDMA users will get the best frequencies with the least amount of noise.
- (e)    • Adjacent subcarriers: requires measurements to find the best channels but ICI (inter-carrier interference) is reduced
- Regularly spaced subcarriers: Provides diversification of SNR
- Randomly spaced subcarriers: Offers all the benefits of regularly spaced subcarriers as well as reduced adjacent cell interference
- (f)    (1) Resiliency against narrow band interface
- (2) Relatively high security

- (3) Receiver can separate each user based on code
- (g) Spread spectrum encodes the signal and then the bandwidth of the signal is increased to reduce jamming of the signal. Thus, the bandwidth is wider after the signal has been encoded.
- (h) The bandwidth of the signal increases proportionally with the bit rate
- (i) CDMA is "Code Division Multiple Access" and is a spread spectrum technique that allows for signals with a higher bandwidth as well as multiple users to be multiplexed over the same channel.
- (j) Subcarrier spacing:  $\frac{1}{T} = \frac{1}{16.67\mu S} = 14.999kHz$   
 Number of required subcarriers:  $\frac{bitrate}{subcarrierspacing} = \frac{20 \times 10^6}{10 \times 10^3} = 1333.333$ ,  
 approximating to **1334 subcarriers**
- (k)  $C = B \log_2 1 + SNR$
- For  $SNR = 0.1$   
 $B = 0.4MHz$
  - For  $SNR = 0.01$   
 $B = 3.9MHz$
  - For  $SNR = 0.001$   
 $B = 38.84MHz$

## 4 Coding and Error Control

- (a) 0110111 = 0110
- (b) 1010101 = 1010
- (c) 1110011 = 1110
- (d) 1110110 = 1110
- (e) 1111100 = 1111

## 5 Wireshark

- (a) (1) Host IP: 192.168.86.38  
 Destination IP: 74.6.228.140
- (2) ICMP packets have a type and a code because it communicates network layer information, not application layer. The type and code identify the message being received. The network software interprets the messages so no port numbers are needed to direct the messages to a process.

```

→ ~ ping -c 10 www.yahoo.com
PING atsv2-fp-shed.wg1.b.yahoo.com (74.6.228.140): 56 data bytes
64 bytes from 74.6.228.140: icmp_seq=0 ttl=50 time=46.646 ms
64 bytes from 74.6.228.140: icmp_seq=1 ttl=50 time=47.565 ms
64 bytes from 74.6.228.140: icmp_seq=2 ttl=50 time=46.248 ms
64 bytes from 74.6.228.140: icmp_seq=3 ttl=50 time=51.563 ms
64 bytes from 74.6.228.140: icmp_seq=4 ttl=50 time=49.739 ms
64 bytes from 74.6.228.140: icmp_seq=5 ttl=50 time=47.655 ms
64 bytes from 74.6.228.140: icmp_seq=6 ttl=50 time=51.256 ms
64 bytes from 74.6.228.140: icmp_seq=7 ttl=50 time=49.503 ms
64 bytes from 74.6.228.140: icmp_seq=8 ttl=50 time=47.147 ms
64 bytes from 74.6.228.140: icmp_seq=9 ttl=50 time=51.068 ms

--- atsv2-fp-shed.wg1.b.yahoo.com ping statistics ---
10 packets transmitted, 10 packets received, 0.0% packet loss
round-trip min/avg/max/stddev = 46.248/48.839/51.563/1.921 ms
→ ~

```

Figure 2: ping yahoo.com

No.	Time	Source	Destination	Protocol	Length	Info
185	13.923847	192.168.86.38	192.168.86.1	ICMP	78	Destination unreachable (Port unreachable)
187	181.656970	192.168.86.38	192.168.86.1	ICMP	78	Destination unreachable (Port unreachable)
186	231.128219	192.168.86.38	192.168.86.1	ICMP	78	Destination unreachable (Port unreachable)
188	212.872889	192.168.86.38	192.168.86.1	ICMP	78	Destination unreachable (Port unreachable)
127	283.391883	192.168.86.38	192.168.86.1	ICMP	78	Destination unreachable (Port unreachable)
151	338.515726	192.168.86.38	98.138.219.232	ICMP	98	Echo (ping) request id=84459, seq=8/0, ttl=64 (reply in 15177)
151	338.588464	98.138.219.232	192.168.86.38	ICMP	98	Echo (ping) reply id=84459, seq=8/0, ttl=64 (request in 15174)
152	339.518763	192.168.86.38	98.138.219.232	ICMP	98	Echo (ping) request id=84459, seq=1/256, ttl=64 (reply in 15286)
152	339.599476	98.138.219.232	192.168.86.38	ICMP	98	Echo (ping) reply id=84459, seq=1/256, ttl=64 (request in 15285)
152	340.520998	192.168.86.38	98.138.219.232	ICMP	98	Echo (ping) request id=84459, seq=2/512, ttl=64 (reply in 15283)
152	340.579621	98.138.219.232	192.168.86.38	ICMP	98	Echo (ping) reply id=84459, seq=2/512, ttl=64 (request in 15288)
152	341.520887	192.168.86.38	98.138.219.232	ICMP	98	Echo (ping) request id=84459, seq=3/768, ttl=64 (reply in 15284)
152	341.577388	98.138.219.232	192.168.86.38	ICMP	98	Echo (ping) reply id=84459, seq=3/768, ttl=64 (request in 15291)
153	342.527382	192.168.86.38	98.138.219.232	ICMP	98	Echo (ping) request id=84459, seq=4/1024, ttl=64 (reply in 15322)
153	342.578339	98.138.219.232	192.168.86.38	ICMP	98	Echo (ping) reply id=84459, seq=4/1024, ttl=64 (request in 15321)
153	343.538552	192.168.86.38	98.138.219.232	ICMP	98	Echo (ping) request id=84459, seq=5/1280, ttl=64 (reply in 15368)
153	343.584236	98.138.219.232	192.168.86.38	ICMP	98	Echo (ping) reply id=84459, seq=5/1280, ttl=64 (request in 15371)
153	344.535839	192.168.86.38	98.138.219.232	ICMP	98	Echo (ping) request id=84459, seq=6/1536, ttl=64 (reply in 15385)
153	344.591417	98.138.219.232	192.168.86.38	ICMP	98	Echo (ping) reply id=84459, seq=6/1536, ttl=64 (request in 15383)
154	345.414884	192.168.86.38	192.168.86.1	ICMP	78	Destination unreachable (Port unreachable)
154	345.136248	192.168.86.38	98.138.219.232	ICMP	98	Echo (ping) request id=84459, seq=7/1792, ttl=64 (reply in 15422)
154	345.190526	98.138.219.232	192.168.86.38	ICMP	98	Echo (ping) reply id=84459, seq=7/1792, ttl=64 (request in 15421)
154	346.538888	192.168.86.38	98.138.219.232	ICMP	98	Echo (ping) request id=84459, seq=8/2048, ttl=64 (reply in 15463)
154	346.588828	98.138.219.232	192.168.86.38	ICMP	98	Echo (ping) reply id=84459, seq=8/2048, ttl=64 (request in 15462)
154	347.544238	192.168.86.38	98.138.219.232	ICMP	98	Echo (ping) request id=84459, seq=9/2304, ttl=64 (reply in 15489)
154	347.597912	98.138.219.232	192.168.86.38	ICMP	98	Echo (ping) reply id=84459, seq=9/2304, ttl=64 (request in 15488)
186	169.620378	192.168.86.38	192.168.86.1	ICMP	78	Destination unreachable (Port unreachable)
186	385.312122	192.168.86.38	192.168.86.1	ICMP	78	Destination unreachable (Port unreachable)
186	389.313438	192.168.86.38	192.168.86.1	ICMP	78	Destination unreachable (Port unreachable)

Figure 3: icmp output

- (3) ICMP Type: 8 Echo (ping) request  
Code: 0  
Checksum: 16-bit  
Sequence number: 16-bit  
Identifier: 16-bit

Other fields are the timestamp from the icmp data plus the data itself.

- (4) ICMP Type: 0 Echo (ping) reply  
Code: 0  
Checksum: 16-bit  
Sequence number: 16-bit  
Identifier: 16-bit

Other fields are the timestamp from the icmp data plus the data itself.

- (b) (5) Host IP: 192.168.86.38  
Destination IP: 129.187.255.151
- (6) The protocol number would be 0x11 for UDP instead of 01
- (7) The ICMP traceroute echo packet has the same fields as the ping packets
- (8) The error packet has a different type than the query packets. It also contains the IP header and the first 8 bytes of the ICMP packet that it is describing.

```
➔ ~ traceroute -i tum.de
traceroute to tum.de (129.167.255.151), 64 hops max, 72 byte packets
 1 testvif1.here (192.168.86.1) 3.368 ms 2.646 ms 3.373 ms
 2 ce-24-55-0.1.austin.rtx.as (24.55.0.1) 12.705 ms 14.850 ms 13.380 ms
 3 tge0-0-4.ausgft01h.texas.rtr.com (66.68.3.233) 29.526 ms 31.616 ms 29.992 ms
 4 agg22.ausutut001r.texas.rtr.com (129.175.43.211) 14.413 ms 17.470 ms 12.210 ms
 5 agg22.dl1st01301r.texas.rtr.com (24.175.41.46) 25.179 ms 23.835 ms 23.672 ms
 6 bu-ether44.llnwd3761w-bcr00.tbone.rtr.com (66.109.6.88) 21.697 ms 23.181 ms 16.571 ms
 7 4.68.38.57 (4.68.38.57) 22.132 ms 20.391 ms 15.044 ms
 8 ae-1-5.bar1.hamburg1.level3.net (4.69.142.209) 141.959 ms 146.572 ms 172.240 ms
 9 195.122.181.62 (195.122.181.62) 142.490 ms 140.219 ms 144.063 ms
10 cr-han2-be3-x-win.dfn.de (188.1.144.38) 140.639 ms 144.619 ms 145.588 ms
11 cr-fra2-be12-x-win.dfn.de (188.1.144.133) 149.242 ms 152.413 ms 153.224 ms
12 cr-gar1-be6-x-win.dfn.de (188.1.145.230) 158.799 ms 164.031 ms 164.918 ms
13 kr-gar188-0-x-win.dfn.de (188.1.37.90) 151.360 ms 155.967 ms 153.420 ms
14 vl-3001.cvr2-zwr.lrz.de (129.107.0.168) 152.463 ms 148.854 ms 152.816 ms
15 wwwv1.tum.de (129.167.255.151) 166.111 ms 161.505 ms 160.091 ms
```

[illegible]

Figure 5: traceroute wireshark output

151.	3838.305316	192.168.86.38	129.187.255.151	ICMP	86 Echo (ping) request	id=80480, seq=43/11888, ttl=15 (reply in 151891)
151.	3838.531201	129.187.255.151	192.168.86.38	ICMP	86 Echo (ping) reply	id=80480, seq=43/11888, ttl=23 (request in 151892)
151.	3838.531218	192.168.86.38	129.187.255.151	ICMP	86 Echo (ping) request	id=80480, seq=44/11264, ttl=15 (reply in 151891)
151.	3838.693518	129.187.255.151	192.168.86.38	ICMP	86 Echo (ping) reply	id=80480, seq=44/11264, ttl=23 (request in 151848)
151.	3838.693783	192.168.86.38	129.187.255.151	ICMP	86 Echo (ping) request	id=80480, seq=45/11528, ttl=15 (reply in 151892)
151.	3838.853075	129.187.255.151	192.168.86.38	ICMP	86 Echo (ping) reply	id=80480, seq=45/11528, ttl=23 (request in 151892)
151.	3840.432811	192.168.86.38	192.168.86.1	ICMP	78 Destination unreachable	(Port unreachable)
151.	3841.855378	192.168.86.38	192.168.86.1	ICMP	78 Destination unreachable	(Port unreachable)
151.	3127.911864	192.168.86.38	192.168.86.1	ICMP	78 Destination unreachable	(Port unreachable)
151.	3127.911905	192.168.86.38	192.168.86.1	ICMP	78 Destination unreachable	(Port unreachable)
151.	3133.763008	192.168.86.38	192.168.86.1	ICMP	78 Destination unreachable	(Port unreachable)
151.	3133.765008	192.168.86.38	192.168.86.1	ICMP	78 Destination unreachable	(Port unreachable)
151.	3159.487707	192.168.86.38	192.168.86.1	ICMP	78 Destination unreachable	(Port unreachable)
151.	3159.511508	192.168.86.38	192.168.86.1	ICMP	78 Destination unreachable	(Port unreachable)
151.	3272.739286	192.168.86.38	192.168.86.1	ICMP	78 Destination unreachable	(Port unreachable)
151.	3342.249359	192.168.86.38	192.168.86.1	ICMP	78 Destination unreachable	(Port unreachable)
Internet Protocol Version 4, Src: 129.187.8.168, Dst: 192.168.86.38						
Internet Control Message Protocol						
Type: 13 (Time-to-live exceeded)						
Code: 0 (Time to live exceeded in transit)						
Checksum: 8a7ff (correct)						
(Checksum Status: Good)						
Unused: 00000000						
Internet Protocol Version 4, Src: 192.168.86.38, Dst: 129.187.255.151						
Internet Control Message Protocol						
Type: 8 (Echo (ping) request)						
Code: 0						
Checksum: 8c1fd (unverified) [in ICMP error packet]						

Figure 6: traceroute error wireshark output