ECE/CS 439
Homework 2: Wireless Basics
Due 31 October 2017

1 Write True/False with a brief justification. Make assumptions where necessary and state them clearly: (6 X 5 = 30)

A: In QAM based wireless communication, the number of symbols per second (baud rate) is a function of the available bandwidth.

B: In QAM based wireless communication, the number of bits per symbols is a function of the available bandwidth.

C: OFDM communicates over N orthogonal frequencies (called subcarriers), hence it must use N antennas, one for each frequency.

D: Consider 802.11 protocol with random counter based channel access. The utility of the medium would first increase and then decrease as a function the number of nodes in the system.

E: (Optional question) With *SleepWell*, write true/false for each of the statements below with justification.

- Latency decreases
- Throughput increases
- Energy savings increase

F: Slot size for counting down in randomized backoff can be smaller than the maximum signal propagation delay in the network.

2 Beamforming-I (10)

Consider two antennas A and B separated by a distance of $\frac{\lambda}{2}$, and transmitting in-phase signals of wavelength λ. A receiver R is placed on a line passing through the mid-point of the two antennas and making an angle θ relative to them as shown in Figure 1. Determine the phase difference between signals of A and B that arrive at R. Plot the phase difference as a function l, when l varies from 0 to 100λ (provide three plots for three different values of θ - 0, 90, and 45).

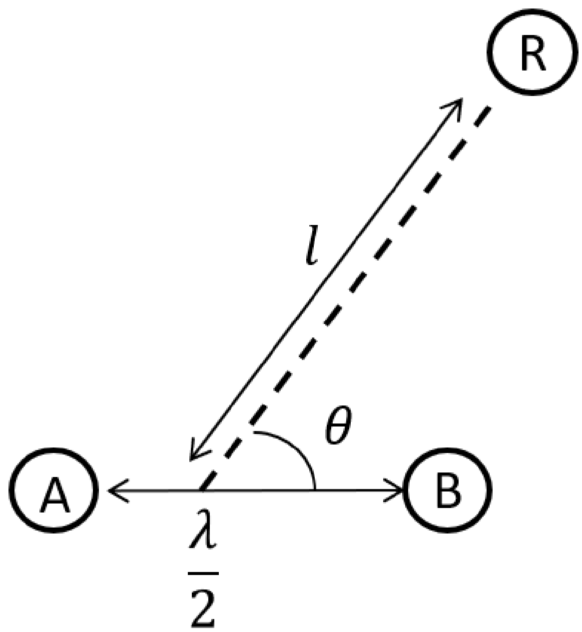

Figure 1: Antenna pair

3 Beamforming-II (15)

Consider a uniform linear array of N antennas as shown in Figure 2. The antenna separation is d as shown, and all antennas transmit signals in phase, at a wavelength of λ. Consider a receiver at an angle θ very far away from the antenna array. Since the receiver is far, we can assume that lines joining the antennas to the receiver are parallel to each other, making an angle θ above the horizontal line. Find all angles θ_{null} where the sum of arriving signals from all antennas add up to 0, creating a perfect null.

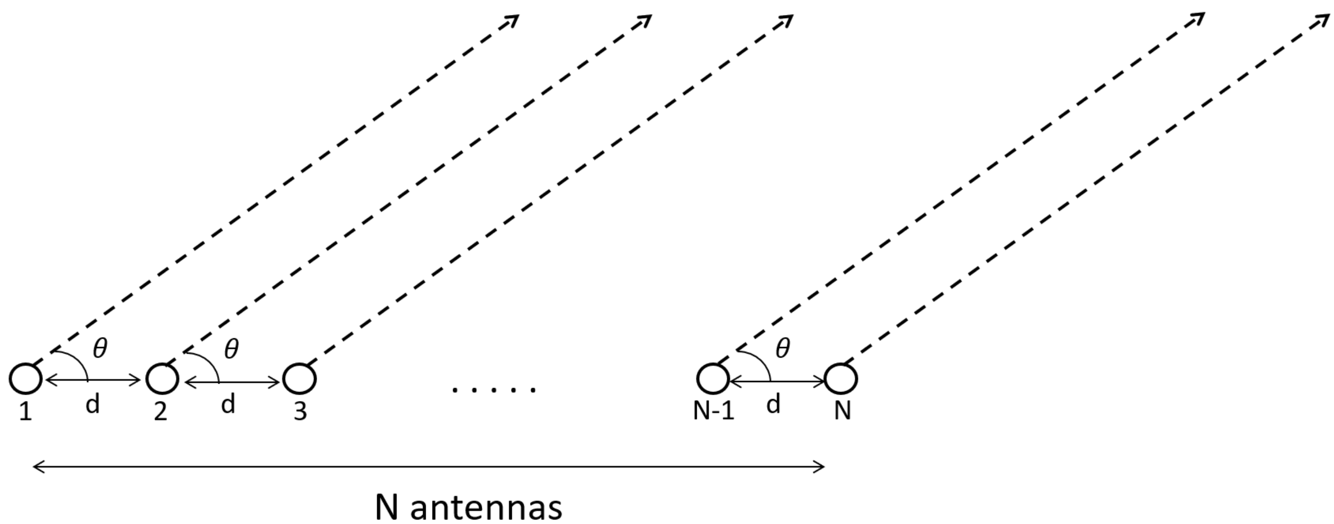

Figure 2: Antenna array

4 Rate control (15)

Suppose you transmit a packet consisting of 5 data symbols and 3 redundant symbols for the purposes of error correction. Because of the redundancy, the receiver can decode all the symbols correctly as long as it receives any 6 or more of the 8 transmitted symbols correctly.

We now introduce a new metric called *dispersion*. Suppose a symbol $\vec{t} = 3 - 1i$ was transmitted based on a QAM modulation. Because of noise, and distortions in the channel, the received symbol at the receiver was $\vec{r} = 3.2 - 1.1i$. The difference $\vec{d} = \vec{r} - \vec{t} = 0.2 - 0.1i$ is called the *dispersion* of the channel. In other words, the received symbol $\vec{r} = \vec{t} + \vec{d}$. If d is low, the symbol would be mapped correctly to its bits, otherwise, there may be errors. For example, the *dispersion* $\vec{d_1}$ is low in Figure 3(a), so the transmitted symbol ($\vec{t_1} = 1 - 1i$) is decoded correctly as 1101. However, in Figure 3(b), the *dispersion* $\vec{d_2}$ is high enough to cause incorrect decoding of the symbol $\vec{t_1}$ as 1001.

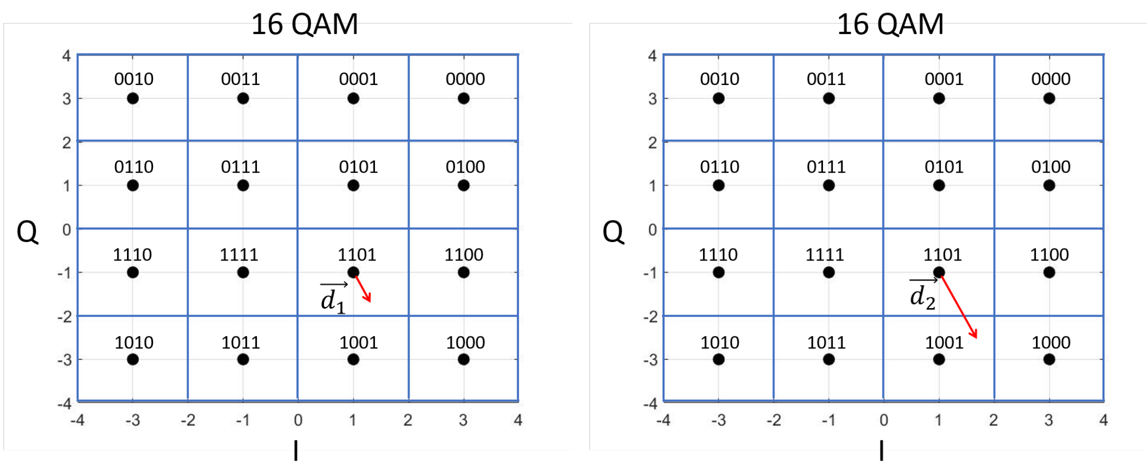

Figure 3: Channel dispersion results in no error (a), causes error (b)

Suppose a transmitter has predicted the following dispersions for 8 symbols it would transmit. $[0.4970+0.5760i, -0.3471-0.1771i, 0.4611-0.3750i, 0.2999+1.1440i, 0.0026+0.0061i, 0.1322+0.1071i, 0.1777+0.9221i, 1.1458-0.1548i]$

You have a choice among BPSK, QPSK, and 16QAM for modulation at the transmitter (shown in Figure 4). Pick the best modulation that allows the highest data rate where atleast 6 of the transmitted symbols can be received correctly (For sake of simplicity, assume that a dispersion of outer symbols as shown in Figure 5 will cause an error).

Similarly, find the best modulation for the following dispersions.

- $[-1.1060-0.6606i, -0.6343+0.4213i, 0.8692+1.0015i, -0.3148-0.0896i, -1.9127-0.2194i, 0.0733-0.6894i, 1.8146-0.8009i, 0.3974+0.2512i]$

- $[0.1636-2.4676i, -0.4199+1.0603i, -0.7282+1.0495i, -1.1825+1.5902i, 1.1519+1.4941i, 4.9096-0.8516i, 1.7176-1.1025i, -3.5888-1.4198i]$

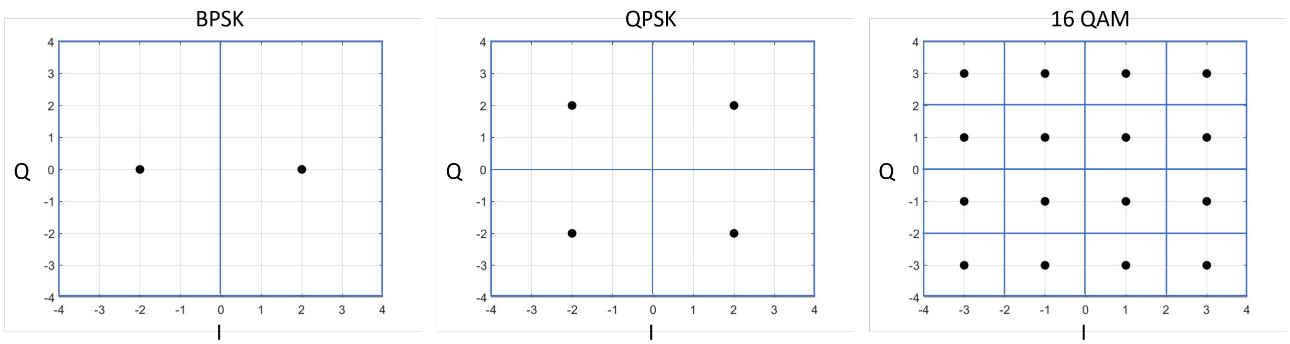

Figure 4: Constellation diagrams for BPSK (a), QPSK (b), and 16QAM (c)

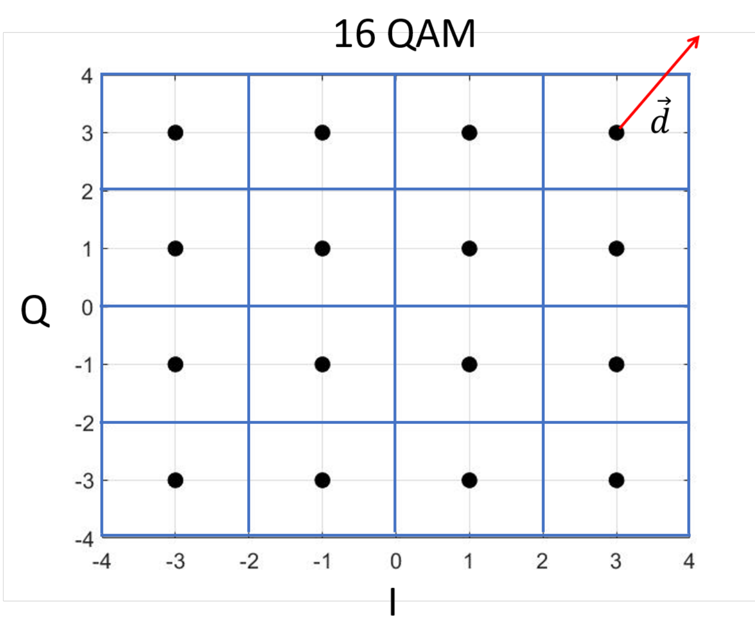

Figure 5: Outer symbol dispersion

5 TDMA scheduling (10)

A set of network topologies is shown in Figure 6. Suppose all odd numbered nodes are transmitters, and even numbered nodes are receivers, determine the link interference graph that includes each possible transmitter to receiver link. Come up with a TDMA schedule for these links using graph coloring (Two links with different colors cannot be scheduled in parallel)

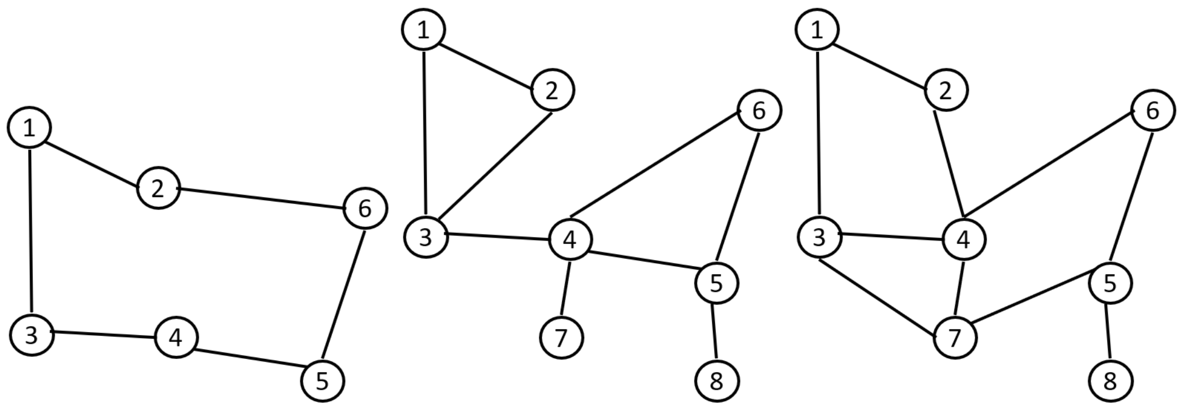

Figure 6: Node connectivity graph

6 OFDM decoding (10)

Below given is a set of 16 downconverted, and downsampled I,Q samples in the form of I+jQ.

- $[-1.1250+0.6250i, -0.6856-1.0786i, -0.2286+0.0518i, -0.1426-0.1738i, 0.1250-0.1250i, 0.6064+0.1341i, 0.3018+0.4786i, -0.1841+0.5210i, -0.3750+0.3750i, 0.5089+1.1518i, 0.4786-0.3018i, 0.3194-0.2530i, -0.1250+0.1250i, -0.4296+0.2926i, -0.0518-0.2286i, 0.0073-0.5942i]$
- $[-1.3750+0.8750i, 0.3276-0.2039i, -0.0884-0.7437i, 0.6804-0.4068i, -0.2500-0.7500i, 0.4890+0.1362i, 0.6187+0.3902i, -0.1344-0.4494i, -1.3750+0.1250i, -0.1508+0.0271i, 0.0884+0.4937i, -0.8572+0.2300i, 0.0000+0.7500i, -0.6658+0.0406i, -0.6187-0.1402i, 0.3112+0.6262i]$
- $[-1.3750+0.1250i, 0.1560-0.7033i, -0.1250+0.7589i, -0.3474+0.4705i, 0.1250+0.1250i, -0.2517-0.2396i, -0.6553+0.8321i, 0.3870+0.7990i, -1.1250+0.8750i, 0.0207+0.2766i, -0.1250-1.0089i, 0.1706-0.3973i, -0.1250-0.1250i, 0.0749+0.1663i, 0.4053-0.5821i, -0.2102-0.3722i]$
- $[-1.2500+0.1250i, 0.4724+0.3162i, 0.1768+0.0518i, 0.1603+1.0842i, 0.0000+0.1250i, 0.3352-0.3913i, 0.3536+0.1250i, -0.4119-0.0292i, -1.0000+0.8750i, -0.0456-0.7430i, -0.1768-0.3018i, -0.0871-1.0110i, 0.2500-0.1250i, -0.2620+0.3181i, -0.3536+0.1250i, 0.8386+0.4560i]$

If the transmitter used a 16 channel OFDM modulation with 16 QAM, can you decode the transmitted message (use standard 16QAM constellation shown in Figure 4(c)). The transmitted message is a 8 character word. Each character is transmitted in the form of a binary ASCII string ('01100001' is the ASCII binary code for character 'a'). The first 4 bits of the first character were modulated as a 16QAM symbol and loaded on the negative most frequency. The last 4 bits of the first character were modulated as a 16QAM symbol and loaded on the second most negative frequency. The first 4 bits of the second character were modulated as a 16QAM symbol and loaded on the third most negative frequency. Similarly, the last 4 bits of the last character were modulated as a 16QAM symbol and loaded on the positive most frequency. The other characters are similarly loaded on frequencies in between.

7 Flow in the middle (10)

Consider the topology shown in Figure.7. Transmitters A, B and C are communicating with receivers D, E, and F respectively. Dotted circles indicate the range of communication for each transmitter. Specifically, transmitters A and C can sense B, but they cannot sense each other. However, B can sense both A and C. Assume that all transmitters are running basic 802.11 protocol for channel contention. Comment on the fairness of the three flows. Do you think the middle flow ($B \rightarrow E$) gets a fair share ($\frac{1}{3}$ of the channel time) or whether it is completely starved and not get any channel time at all? Explain why or why not. Assume all flows are fully backlogged (they have packets to be sent constantly)

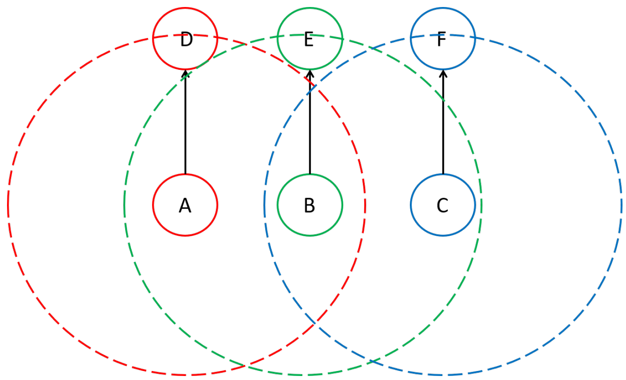

Figure 7: Flow in the middle topology