Quiz 7 - MUMIMO and Beamforming

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1. What is “Multiplexing gain”?

   The improvement in data rate by exploiting DoF to deliver multiple streams concurrently. In other words, send multiple packets simultaneously through multiple paths.

2. What is “Diversity gain”?

   The improvement in signal quality by exploiting path diversity to increase SNR of a single stream. In other words, send a single packet through multiple paths.

3. What is the
   1. Degree of Freedom (DoF)

      For a N x M MIMO channel, DoF = min{N, M}. The channel can transmit at most DoF streams.
   2. Diversity of a 4x2 MIMO system

      Diversity = $4 \times 2 = 8$

4. Why should the antennas of a MIMO node be separated by at least half wavelength?

   To achieve spatial diversity and reduce correlation between the signals. At half-wavelength separation, the phase difference between the signals is significant enough to create different signal paths.

5. What does mmWave mean?

   Higher frequency electromagnetic waves with wavelength in the millimeter range.

6. List two key properties of mmWave communications.
   1. Huge amount of available bandwidth
   2. Short transmission range due to small wavelength

7. Why antenna array (device with a large number of antenna elements) is only practical for mmWave, instead of conventional cmWave spectrum?

   Since the antennas in the array must be separated by at least half wavelength, the antenna array for cmWave will be too large for any portable device.

8. Define what is “transmit beamforming” and “receive beamforming”, respectively.

   Transmit beamforming is a signal processing technique used at the transmitter to direct the transmission of signals in specific directions. It is achieved by adjusting the phase and amplitude of the signals.

   Receive beamforming is a signal processing technique used at the receiver to enhance the reception of signals from a specific direction. By applying a set of weights to the received signals, the receiver can focus on the signal from the desired direction.

9. Explain what does “beam scanning” mean.

Beam scanning is the process of steering a beam of signal in different directions by adjusting the phase and amplitude of the signals from each antenna.

10. Compare a 16-antenna and 64-antenna array. Which one can generate a narrower beam?

A 64-antenna array can generate a narrower beam. Because a 64-antenna array has more antenna elements, which enhances the array’s ability to focus the energy (increased $G_{tx}G_{rx}$).

11. Describe what is “digital beamforming” and “analog beamforming”.

Analog beamforming is the beamforming process performed in the analog field (before ADC). Some phase variation is done to the analog signals to create a narrow beam.

Digital beamforming is the beamforming process performed in the digital field (after ADC). Transmitter uses its antennas to actively cancel the interfering streams at a particular client. Then the receiver can calculate the decoder through CSI and get the signal.

12. If a transmitter has 2 RF chains and is equipped with a 16-antenna array.
    1. What is the maximum number of parallel streams it can send?

       The maximum number of parallel streams = min{2,16} = 2
    2. Say the transmitter sends two streams x using “hybrid beamforming”. Let F_{bb} and F_{rf} denote the digital beamforming precoder and analog beamforming vector. It then transmits $F_{rf}F_{bb}$x. The receiver with a 8-antenna array receives the signals $y = \mathrm{H}F_{rf}F_{bb}$x.

       Q: What are the dimensions of the received signal y, the channel matrix H and precoders F_{rf} and F_{bb}?

       y: 8×2

       H: 8×16

       F_{rf}: $N_t \times N_{RF} = 16 \times 2$

       F_{bb}: $N_{RF} \times N_s = 2 \times 2$