Learning Objective 7.1: I can describe QAM and OFDM and identify use cases for each.

Show your work. Write a **Documentation** line at the end (**None** if you did not collaborate).

1. **Reading constellations.** A link sends 10,000 symbols per second with RRC pulses of roll-off $\alpha = 0.25$. Its constellation display shows, at different times, a grid of 4 by 4 points and a grid of 8 by 8 points, both scaled to the same average power.

   (a) Name each constellation and find its bits per symbol and its bit rate.

   16-QAM:

   64-QAM:

   (b) Find the occupied bandwidth with each constellation.

   (c) In words, explain how a QAM constellation differs from Lesson 15's 8PSK, and why a QAM receiver needs an AGC that a PSK receiver can do without.

2. **Watching the noise.** You run `L20-qam-noise.grc` and raise the Noise amplitude slider, which adds the same noise to the QPSK, 16-QAM, and 64-QAM rows.

   (a) At one setting, the QPSK display shows four round clouds well apart, the 16-QAM display shows sixteen clouds with gaps between them and a few stray points, and the 64-QAM display shows one square of scattered dots with no gaps. Describe what a receiver decoding each signal would deliver at this setting.

   (b) The noise is the same in all three rows. In words, explain why the three displays look so different.

   (c) A link carries 64-QAM cleanly at short range. In words, describe what you would see on its constellation display as the receiver moves away, and what Wi-Fi or LTE does at that point.

3. **An OFDM spectrum and its guard.** A 20 MHz 802.11g Wi-Fi channel uses the subcarrier layout of `L20-ofdm-link.grc`: a 64-point FFT, subcarriers -26 to 26 with the one at 0 Hz left empty, and a 16-sample guard. It runs at 20 million samples per second.

   (a) Find the subcarrier spacing and the width of the occupied band, from the center of subcarrier -26 to the center of subcarrier 26.

   (b) Find the length of the guard in microseconds.

   (c) `L20-ofdm-link.grc` uses the same 16-sample guard at 100,000 samples per second. Find the guard's length there, and the delays of its Echo delay slider at 8 and at 20 samples. Which echo ends inside the guard?

   (d) In words, describe what `L20-ofdm-link.grc` showed for an echo inside the guard and for one past it: the spectrum, the points after the equalizer, and the text.

4. **Recognizing signals on a waterfall.** For each description, name the system and whether it uses OFDM or a single carrier, and give one feature that identifies it.

   (a) A PlutoSDR at 20 MS/s tuned to 2.437 GHz shows short bursts that come and go. Most have a flat top about 17 MHz wide with steep edges and a small dip at the center of each burst, which moves with the burst when you retune.

   (b) The same PlutoSDR tuned to 740 MHz shows a flat band about 9 MHz wide with steep edges, which stays on.

   (c) A PlutoSDR at 2 MS/s tuned to an FM station shows a rounded signal whose width changes with the audio, with a flat shelf of constant width on each side from about 130 to 200 kHz from its center.

   (d) A cable modem uses 256-QAM. In words, explain why you cannot find its signal with an SDR and an antenna, and why it can use a single carrier.

5. **Choosing a scheme.** For each use case, choose OFDM or a single carrier, and choose QPSK, 16-QAM, or 64-QAM. Explain each choice in a sentence or two.

   (a) A 20 MHz-wide data link inside a large metal hangar, where reflections arrive up to 1.5 μs after the direct signal and the signal is strong.

   (b) A telemetry downlink from a small drone at the edge of its range, in open country with no reflectors nearby, where the signal is weak.

   (c) A point-to-point link between two towers with dish antennas aimed at each other, a clear line of sight, and a strong signal.

   (d) In words, state what decides OFDM or a single carrier, and what decides the number of constellation points.