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Lecture 3: Wireless Channels and Modulation

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1 Overview

These notes will provide a brief overview of End-to-End (E2E) Communication Systems, Wireless Channels, and OFDM.

Recall that in networks, we have several layers

End to End (E2E)
Network layer
MAC/Link layer
Physical layer

In Lecture 2, we discussed the link layer. This lecture on wireless channels and wifi and most of the class will focus on the physical layer, which allows us to transfer from the physical layer to analog.

This lecture expands on background reading from [1, 2].

2 End to End Communication System

From the big picture, we want to take bits, do something to them, and retrieve bits at the receiver. This involves several components

- Modulator: process of converting bits to symbols
- Demodulator: process of converting symbols to bits
- Digital to analog converter (DAC): converts from digital to analog
- Model: Modulator and demodulator together

2.1 Binary Phase Shift Key (BPSK)

Consider the following encoding

bit	symbol
0	-1
1	+1

Similarly, we could encode two bits into symbols using imaginary components.

bits	symbol
00	-1 - i
01	1 - i
10	-1 + i
11	1 + i

We can use **Quadrature Amplitude Modulation** (QAM) as a method to combine two signals into a single channel.

Before transmitting over the air, we can add a **carrier wave**, which involves multiplying by $\cos(2\pi fct)$ where fc is the carrier wave. We need a carrier wave in order to choose different frequencies to prevent collisions. This depends on three factors: 1) We need to do frequency division multiplying. 2) A large antenna size is necessary ($\lambda/4$ where λ is wavelength), and 3) Regulations allow each technology to have a narrow bound because the spectrum is a precious resource. For example, Verizon would get 1.1 gHz to 1.2 gHz.

Note that if we multiply by a carrier wave, we would also need to multiply by $\cos(2\pi fct)$ when we receive as well.

3 Wireless Channel

When we transmit a signal x over the air, it will attenuate, rotate, and add noise. We can describe the output $y(t)$ as

$$y(t) = hx(t) + o(t)$$

where h refers to the channel and is a complex number and o refers to noise. Attenuation and rotation come from h whereas noise comes from n.

In order to estimate the transmitted $x(t)$, we consider that if we knew h, then we could say $x(t) \approx y(t)/h$. To estimate a channel, we then send a known series of symbols ("preamble").

transmitter sends	$x(0)$
receiver gets	$y(0) = hx(0) + n$

Receiver also knows $x(0)$ and receives $y(0)$. We can then estimate $h \approx y(0)/x(0)$. We can reduce the noise over several estimates to get $\hat{h}$.

In channels in which there is a lot of noise (high value for n), it is better to go with a lower bit/symbol modulation, such as BPSK, because a lower SNR is required. For modulations with more bits/symbol a stronger signal is needed for decoding.

3.1 Attenuation and Rotation

So, how do attenuation and rotation effect the signal? Attenuation refers to a signal losing power as it travels the distance of the channel, so over long distances the signal will become quite weak.

Rotation refers to a signal changing phases as it traverses a channel, similar to the phase changes of a sine wave. The reason the received signal may be rotated is because the receiver may get the signal at a different phase than the phase at which the signal was transmitted.

Putting all this together, the channel can be represented with the following equation:

$$h = \frac{1}{d} e^{j2\pi d/\lambda} \tag{1}$$

Traversing a channel gets further complicated with the presence of reflectors. Figure 2 below shows an example of a channel with 1 reflector. Reflections are not ideal because they can allow signals to reach their destination is multiple ways causing a phenomenon called multipath, which is risky because it can cause constructive or destructive interference.

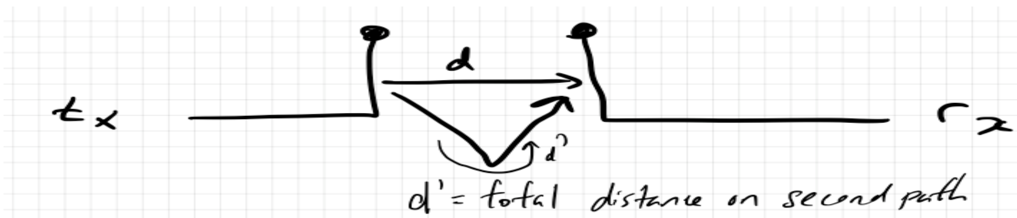

Figure 1: Channel with 1 Reflector

The value h, channel, for Figure 2 can be written as follows:

$$h = \frac{1}{d} e^{j2\pi d/\lambda} + \frac{1}{d'} e^{j2\pi d'/\lambda}, d \approx d' \tag{2}$$

$$h = \frac{1}{d} e^{j2\pi d/\lambda} (1 + e^{j2\pi \Delta d/\lambda}) \tag{3}$$

Using (5), we get constructive interference when:

$$h = \frac{1}{d} e^{j2\pi d/\lambda} (1 + e^{j0}) = \frac{2}{d} e^{j2\pi d/\lambda} \tag{4}$$

Using (5), we get destructive interference when:

$$h = \frac{1}{d} e^{j2\pi d/\lambda} (1 + e^{j\pi}) = 0 \tag{5}$$

4 Wifi physical layer (OFDM)

OFDM is the process in which the bandwidth of a channel can be divided into different subcarriers, such that each subcarrier can support different modulations. Therefore, parts of a signal can be divided into the subcarriers with each part being optimized for that parts SNR. So, if a particular part has low power, it would be good to modulate that part with BPSK to limit BER.

Consider the example shown in the figure below that was covered in class. It shows how a signal with two complex symbols would be modulated using ODFM.

References

[1] Robert Gallager, course materials for 6.450 Principles of Digital Communications I, Fall 2006. MIT OpenCourseWare (http://ocw.mit.edu/), Massachusetts Institute of Technology. Downloaded on 20 September 2017.

[2] Tan, Jit Ken. (2003). An Adaptive Orthogonal Frequency Division Multiplexing Baseband Modem for Wideband Wireless Channels. Unpublished master?s thesis, Massachusetts Institute of Technology, Cambridge, MA.

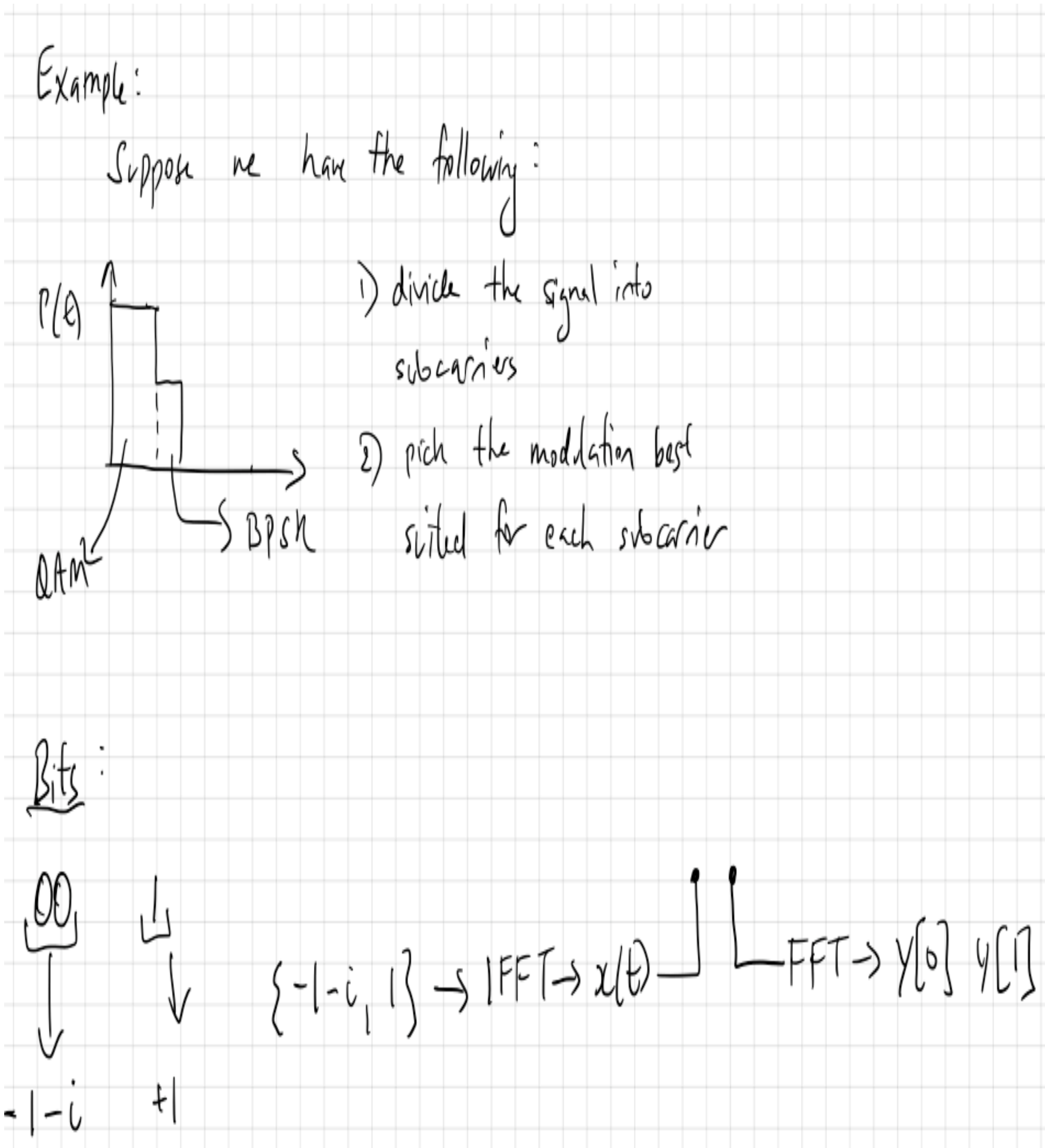

Figure 2: ODFM Example