ECE 5325/6325: Wireless Communication Systems
Lecture Notes, Spring 2010

Lecture 19

Today: (1) Diversity

- Exam 3 is two weeks from today. Today's is the final lecture that will be included on the exam.
- HW 8 was due Friday, April 2. I'd like to extend the HW 8 deadline to Tuesday, April 6, at the start of class, and include the material for today on HW 8. This way, we can return it earlier, and be ready earlier, for Exam 3.

1 Diversity

Diversity is the use of multiple channels to increase the signal to noise ratio in the presence of random fading losses. The idea of diversity is "don't put all of your eggs in one basket".

For fading channels, we know that there is a finite probability that a signal power will fall below any given fade margin. For a Rayleigh channel, we showed that to have the signal above the required SNR 99% of the time, we needed to include a fade margin of 18.9 dB. This is a big "loss" in our link budget. For example, if we didn't need to include the fade margin in the link budget, we could multiply the path length by a factor of $10^{18.9/20} \approx 10$ (in free space); or increase the number of bits per symbol in the modulation significantly higher so that we can achieve higher bit rate for the same bandwidth.

There are several physical means to achieve multiple channels, and to get those channels to be nearly independent. Each has its advantages and disadvantages.

Space Diversity Space diversity at a receiver is the use of multiple antennas across space. Because multipath fading changes quickly over space (see lecture notes on fading rate, and Doppler fading), the signal amplitude received on the different antennas can have a low correlation coefficient. The low correlation typically comes at separation distances of more than $\lambda/2$, where λ is the carrier wavelength. The Jakes model (equal power from all angles) says that the correlation coefficient at $\lambda/2$ is exactly zero; however, in reality, this is not true. The actual angular power profile (multipath power vs. angle) determines the actual correlation coefficient. In general, we either accept that the correlation coefficient is not perfectly zero, or we separate the antennas further than $\lambda/2$. What is $\lambda/2$ at typical carrier frequencies?

The problems with space diversity are most importantly that for consumer radios, we want them to be small; and multiple antennas means that the device will be larger. This is fine when space is not a big concern – for base stations, or for laptops and access points. Another problem is, in general, a receiver with multiple antennas must have one RF chain (downconverter, LNA, filter) per antenna. An exception is that a receiver can use a scanning combiner, which has an RF switch that scans between antennas, and switches when the SNR goes low.

The benefits of space diversity are that no additional signal needs to be transmitted, and no additional bandwidth is required.

Space diversity could be used at a transmitter, by changing the transmit antenna until the receiver SNR is high enough. However, this requires some closed loop control, and so is less common.

MIMO is a kind of space diversity and multipath diversity, that is more beneficial than simple diversity method we cover in this lecture. We will cover it in our final lecture.

The multiple antennas don't need to have the same gain pattern. Another method of diversity is gain pattern diversity, although it is not mentioned in the book.

Polarization Diversity Polarization diversity is the use of two antennas with different polarizations. We know that reflection coefficients are different for horizontal and vertically polarized components of the signal. Scattered and diffracted signal amplitudes and phases also are different for opposite polarizations. Thus we can consider one polarized signal, which is the sum of the amplitudes and phases of many reflected, scattered, and diffracted signals, to be nearly uncorrelated with the other polarized signal.

The advantages of polarization diversity is that the two antennas don't need to be spaced $\lambda/2$ apart, so polarization diversity can possibly be done on a mobile device. It may be combined with space diversity so to further reduce the correlation coefficient between the signal received at two antennas. Polarization diversity, like space diversity, doesn't require any additional bandwidth or signal transmission from the transmitter.

The disadvantages are simply that there can be only two channels – vertical and horizontal (or equivalently, right-hand and left-hand circular) polarizations. It may require two receiver RF chains (again, unless a scanning combiner is used).

Frequency Diversity Frequency diversity uses multiple transmissions on different center frequencies. This doesn't typically mean transmitting exactly the same thing on multiple different bands (which would require multiple times more bandwidth!). Frequency division multiplexing (FDM) or orthogonal FDM (OFDM) are the typical examples, which divide the data into N different bands. Error correction coding is used so that some percent of errors can be corrected, so if a certain percent of the bands experience deep fades, and all of that data is lost, the data can still be recovered during decoding. Frequency bands in FDM or OFDM are typically somewhat correlated – each band needs to be in frequency flat fading so that equalization does not need to be used – but this means that bands right next to each other still have some positive fading correlation.

FH-SS is another frequency diversity example. FH-SS may experience deep fades (and interference) on some center frequencies among its hopping set, but it is unlikely to lose more than a percentage of its data. It also uses error correction coding.

Frequency diversity methods can also be set to control which frequency bands/ channels the transmitter uses, to remove the bands that are in deep fades. Again, this requires closed loop control.

Advantages of frequency diversity are that only one antenna, and one RF chain, is needed. A disadvantage is that, because some of the transmit power is used to send data in bands that are in deep fades, the power efficiency is less compared to space diversity, in which the transmitter sends all of its power in one channel.

Multipath diversity Multipath diversity is the capturing of multipath signals into independent channels. In DS-SS, a rake receiver achieves multipath diversity by isolating multipath components separately from each other based on their differing time delays. If one time delay group fades, another time delay group may not fade. These "fingers" of the rake receiver do not require different RF chains (an advantage compared to space diversity) and benefit most when the multipath channel is the worst, for example, in urban areas, or in mountain canyons. The disadvantage of DS-SS is the large frequency band required – for example, 20 MHz for 802.11b, or 1.25 MHz for IS-95 (cellular CDMA). There is also significant computational complexity in the receiver, although standard ICs now exist to do this computation for these common commercial devices.

The Rappaport book calls this "time diversity", but I think it is confusing – perhaps "multipath diversity" or even "multipath time delay diversity" are better names.

Time Diversity Time diversity is the use of a changing channel (due to motion of the TX or RX) at different times. For example, one might send the same data at multiple different times, but this would require multiple times the transmit power, and reduce the data rate possible on one channel. This incurs additional latency (delay). However, it is used in almost all common commercial sys-