Today: (1) Rake Receiver, (2) Channel Measurement

- Exam 2 has been returned, grades posted on WebCT.
- HW 7 due tomorrow, Friday, March 19.

1 Rake Receiver

We have presented in Lecture 16 the DS-SS signal, which we represent as

\[ s_k(t) = a_k(t)p_k(t)\cos(2\pi f_c t) \]

where \( a_k(t) \) is the bit signal, +1 or -1, which indicates the symbol value being sent, and \( p_k(t) \) is the “pulse shape”, which for DS-SS is a PN signal, as shown in Figure 1.

![Figure 1: A DS-SS transmitter multiplies symbol values by the PN signal and \( \cos(2\pi f_c t) \) to produce the transmitted signal.](image)

Here, we discuss the receiver for a DS-SS signal. We saw at the end of Lecture 16 that the PN signal was nearly orthogonal to itself at different time delays. That is, after the correlator with the PN signal in the receiver, the output has a spike when the PN signal lines up with itself, and is nearly zero at other times. First, assume that there are no multipath. In this case, the received signal would look like what is shown in Figure 2(a). There is one peak corresponding at 0, \( T_s \), 2\( T_s \), and so on. The value of that peak indicates which symbol value was sent.

But in real world channels, multipath will arrive at different time delays. In the DS-SS receiver, this can be measured by looking at the correlator output, as shown in Figure 2(b). Instead of one peak, there are multiple peaks, one at each multipath time delay. (Actually, they may begin to merge together to form fewer wider
Figure 2: (a) A simplified DS-SS receiver (which essentially assumes no multipath exist) correlates the downconverted signal with the PN signal and samples the output each symbol to determine which symbol value was sent. (b) A “rake” DS-SS receiver samples the correlator output at each multipath “peak” in order to benefit from each arriving multipath signal’s power.

The use of the values of the correlator output at multiple time delays is called a rake receiver. In some books, “rake” is written as “RAKE”, but it is not an acronym, it is an analogy to a garden rake. A rake has several “fingers” that each can pick up things simultaneously.

The use of a rake receiver is called “multipath diversity”. Effectively, “diversity” is not putting your eggs all in one basket. In this case, any one multipath may be blocked or may fade. If we use a rake receiver, we don’t completely fail when one multipath component is received with less power. The rake effectively increases the SNR by combining the power contained in different peaks.

2 Channel Measurement

Wideband channel measurement (“small scale multipath measurements” in Rappaport) is the determination of the channel impulse response (CIR) or channel frequency response for a given link. Wideband channel measurement is useful to get inputs required for system design such as correlation bandwidth or RMS delay spread, or to determine how well a diversity method will perform (how well
will a rake receiver work?). But, different frequency bands (e.g., 2.4 GHz vs. 24 GHz), and different environments (e.g., indoor WLANs vs. plane-to-plane communications) will tend to have different characteristics. The only way to really know what a channel is like in a particular environment at a particular frequency is to measure it.

We discussed that the radio channel is a filter in Lecture 9. The *channel impulse response* is given by

\[ h(\tau) = \sum_{i=0}^{M-1} a_i e^{j\phi_i} \delta(\tau - \tau_i) \]  

(1)

where \( a_i \) is the voltage gain, \( \phi_i \) is the phase change, and \( \tau_i \) is the time delay, of multipath component \( i \). Note that name “power delay profile” (PDP) is the name given to a measurement of \( |h(\tau)|^2 \). The *channel frequency response* is

\[ H(f) = \sum_{i=0}^{M-1} a_i e^{j(-2\pi f \tau_i + \phi_i)} \]  

(2)

Rake reception is a good introduction to channel measurement because the rake receiver produces as a by-product information about the amplitude, phase, and time delays of the multipath in the channel, in the output of the correlator. The impulse responses printed in Lecture 9 were generated using the correlator output of a 802.11b receiver that we built in our lab using a software radio [1].

The Rappaport book relates three other types of measurement systems:

1. **Direct RF Pulse System**: We can’t send \( \delta(\tau) \), a true impulse, through the air – it would be interference in every frequency band. But, we can send a rectangular pulse with a narrow pulse width, as an approximation. When the pulse is received, it will be the convolution of \( h(\tau) \) in (1) and the original pulse shape. This still does require producing a lot of interference, so it is not a popular method.

2. **DS-SS Sliding Correlator**: The DS-SS sliding correlator sends a DS-SS signal from the transmitter with no data \( (a_k(t) = 1 \) for all \( t \)). The receiver is *not* a rake receiver. The problem with a rake receiver is that it is computationally complex. It requires doing many multiplies and adds each sample. If the measured bandwidth is high (say, a few hundred MHz), then the required computational power may be too high for standard hardware. The DS-SS sliding correlator dramatically slows down the computational requirements. It uses a slower chip rate \( \beta \) in the PN signal generator in the receiver than in the transmitter (denote the transmit chip rate as \( \alpha > \beta \)). This effectively slows down the correlation to the *difference* between the PN signal generator chip rates, \( \alpha - \beta \). For example, the transmit
chip rate might be $\alpha = 100$ MHz, but the receiver might have chip rate $\beta = 99.99$ MHz, for a difference $\alpha - \beta = 10$ kHz, $10^4$ times slower than $\alpha$. Now, the correlator output traces out the measured channel impulse response each $1/(\alpha - \beta)$. An example is shown in Figure 3. Although this figure shows time in $\mu$s, the plot was actually recorded in time $1 \mu$s times $10^4$, or 0.01 second.

(3) **Frequency Domain**: The frequency sweep method simply transmits a CW signal that slowly increases frequency from $f_{\text{min}}$ to $f_{\text{max}}$. Assuming that the transmitted signal had constant amplitude, the amplitude of the received signal thus measures $|H(f)|$. A good way to do this is with a vector network analyzer (VNA). By setting the VNA to measure the s-parameters of the channel, we obtain the gain in the channel, which is $s_{21}$. By having the VNA sweep across input frequencies, we can measure amplitude and phase of $H(f)$ across the band we’re interested in. Note if we really want $h(\tau)$, it is just the Fourier transform of $H(f)$.

**References**
