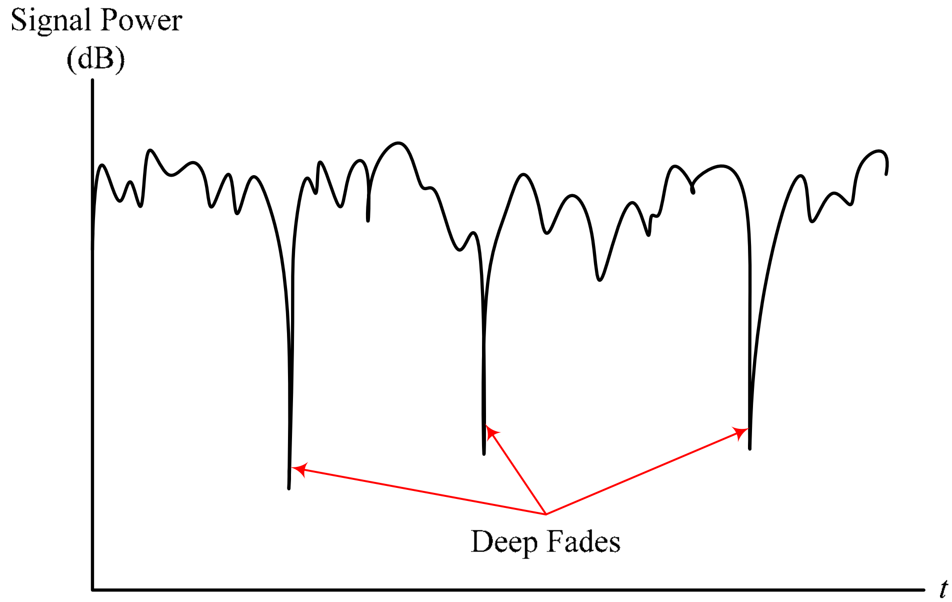
Lecture 21: Mitigation Techniques for Multipath Fading Effects

Diversity

Although equalization can fix a lot of the distortion done by the channel, an equalizer may not be able to amplify a signal that is experiencing a very deep fade. If we look at the power of a received signal as it is experiencing fading, the following would be a typical power profile:



During the time instants where fading is so sever (during deep fades) data that is transmitted may be lost and impossible to recover back. To avoid losing data due to deep fades as much as possible the concept of diversity combining is employed.

The concept of diversity combining states that if multiple receiving (or transmitting) antennas that are spaced from each other by some distance are used to receive (or transmit) a signal, the possibility that deep fades will occur on all antennas at the same time instants is much lower than the probability that deep fades will occur in one of these antennas. Therefore, the signals received from multiple antenna can be combined using one of the diversity combining techniques to reduce the probability of deeps fades significantly, and hence improve the reception quality. In cellular systems, you may have noticed that each sector of a tower uses multiple antennas for transmission/reception (in most cases 3 antennas are used). These antennas provide the diverse signals to improve the reception. There are several method of combining the signals to improve the reception:

1. **Selective Diversity:** In this diversity technique, all signals are first weighted to insure that all have the same SNR, and then the one with the highest magnitude at any particular time instant is used for reception. Therefore, only one signal (the one with the largest power after weighting them to have the same SNR) is being used for reception at any time instant.
2. **Scanning Diversity:** this is similar to the selective diversity except that the different signals are scanned and once one is found to have a signal power above some threshold, it is used for reception regardless of its power ration compared to other signals. Only if the power of the

signal being used for reception drops below the threshold, the scanning process is repeated until another signal with power greater than the threshold is found and so on.

3. **Maximal Ratio Combining:** In this method, the signals are weighted according to their SNR, and then the different signals are added together but only after being co-phased (the different signals are delayed to insure that they all have the same phase to insure constructive addition).
4. **Equal Gain Combining:** This is similar to the Maximal Ratio Combining except that the weighting is set to 1 for all signals.

Channel Coding

After applying all techniques to reduce the loss or corruption of data, including channel equalization and diversity techniques, final detected bits may still contain errors. To reduce the probability of errors in the data, channel coding is used. Channel coding is defined as the addition of an amount of redundancy that helps in detecting and/or correcting errors in the data. Transmitting binary data that may take all bit combinations (for example transmitting 8 bits of data that may take any of 2^8 possible combinations) does not allow the detection or correction of data because any error that occurs in one or more bits produces another possible bit sequence that can transmitted. Adding redundancy causes some bit combinations to be invalid. For example, if 1 parity bit is added to 8 bits, then out of the 2^9 possible combinations of bits, only half of the bit combinations (or 2^8 possible bit combinations) are valid and the rest are not. If one bit is received in error, this will cause the received bit combination to be one of the invalid combinations, and therefore we would be able to detect that there was an error. The more redundancy bits are added to the data, the higher the capability of the code is to detect and/or correct errors (assuming that the code is designed properly).

There are several famous classes of channel coding techniques including the following:

1. **Block Codes:** These are generally the simplest types of codes. In block codes, the data is divided into small blocks of bits (for example 10 bits each) and several redundancy bits (called parity) are added to each block (for example 3 bits of redundancy). Block codes are usually described by a pair of integers (n, k) where (n) is the number of bits in each block including data and redundancy, (k) is the number of data bits in each block, and ($n - k$) is the number of redundancy (parity) bits in each block. The added redundancy may allow the detection of errors without the ability to correct them, or may allow the detection and correction of a smaller number of bits. One of the famous classes of block codes is called Hamming Codes. One of Hamming codes is the Hamming (7, 4) Code. This code is capable or correcting 1 bit of error in each block of 4 bits of data.

   The Hamming (7, 4) encoder is described as follows:
   - Data is broken into blocks of 4 bits (B_1, B_2, B_3, B_4).
   - 3 Redundancy bits are added to each block of 4 data bits to make a block of 7 bits (B_5, B_6, B_7).
   - The value of redundancy bit B_5 is obtained by setting it as even parity of bits B_2, B_3, B_4
   - The value of redundancy bit B_6 is obtained by setting it as even parity of bits B_1, B_3, B_4

- The value of redundancy bit B_7 is obtained by setting it as even parity of bits B_1, B_2, B_4
- The 7 bits (B_1, B_2, B_3, B_4, B_5, B_6, B_7) are transmitted over the channel.

The Hamming (7,4) decoder is described as follows:

- Generate Checksum bits C_1, C_2, C_3 to determine the location of one possible error in the 7 bits of data that were received at the receiver.
- The value of Checksum bit C_1 is obtained by setting it as the even parity of bits B_2, B_3, B_4, B_5
- The value of Checksum bit C_2 is obtained by setting it as the even parity of bits B_1, B_3, B_4, B_6
- The value of Checksum bit C_3 is obtained by setting it as the even parity of bits B_1, B_2, B_4, B_7
- Generate and Error value given by Error = $4*C_1 + 2*C_2 + 1*C_3$
- If the value of the error is
  - Error = 0, No errors detects. All bits are correct
  - Error = 1, B_7 (Redundancy bit) is wrong (flip its value)
  - Error = 2, B_6 (Redundancy bit) is wrong (flip its value)
  - Error = 4, B_5 (Redundancy bit) is wrong (flip its value)
  - Error = 7, B_4 (Data bit) is wrong (flip its value)
  - Error = 6, B_3 (Data bit) is wrong (flip its value)
  - Error = 5, B_2 (Data bit) is wrong (flip its value)
  - Error = 3, B_1 (Data bit) is wrong (flip its value)

As an exercise, take a sequence of 4 bits, generate the 3 redundancy bits of the Hamming (7,4) code as described above, and flip one of the 7 bits and apply the decoding procedure described above. You will find that the error is easily corrected. However, if you flip the value of two bits, the code will fail in correcting the two errors.

2. **Convolution Codes:** In this coding technique, the data is convolved with a particular polynomial (the process is similar to multiplication of two polynomials with each other). The decoding process is simply the division of the received data by the polynomial used in the encoder. If the result in division is 0, there are no errors. If the result of division is non-zero, errors have occurred and the result can be used to determine the location of error.

3. **Turbo Codes:** This coding method uses multiple convolution encoders and decoders along with interleaves (devices that mix the bits so that consecutive bits that are in error become separated from each other). The main advantage of turbo coding over other technique is that the Shannon channel capacity limit is almost reached with turbo coding.