Diversity and Smart Receiving Techniques

- Mobile Radio Channel Impairments:
  - Shadow/Multipath&Doppler/ACI&CCI (Co Channel)
  - Deep fade over short period
  - Cause bit errors => high BER
- Most effective method to combat is to use diversity techniques
- To provide multiple received signals whose fading patterns are different
Diversity and Smart Receiving Techniques (cont.)

- Three techniques are used to improve Rx signal quality and lower BER
  1. Equalization
     - Compensates for ISI from multipath (time dispersive channel)
  2. Diversity
  3. Channel Coding
     - Error Control Coding
     - Can correct or at least detect error by redundancy bit
     - Bit Coding vs. Block Coding (Interleaving)

Channel Coding

- Linear Code/Nonlinear Code
- Linear Block Codes
  - Cyclic codes (e.g., Hamming codes)
  - Repetition codes
  - Parity codes
  - Polynomial codes
  - Reed–Solomon codes
  - Algebraic geometric codes
  - Reed–Muller codes
- Convolutional Codes
Convolutional Code

System diagram of k=3, rate=1/3 convolutional encoder consisting of a 3 bit shift register and modulo 2 adders (XOR)

Source: https://www.researchgate.net/figure/System-diagram-of-k3-rate1-3-convolutional-encoder-consisting-of-a-3-bit-shift_fig5_235658269

Diversity and Smart Receiving Techniques (cont.)

• Selection diversity
  – One signal is chosen from diversity branches
  – Usually based on received signal strength

• Linear combining
  – The diversity branches are sum together

• Maximal-ratio combining
  – Each branch is weighted before summing
  – The weight is proportional to the branch RSS
Diversity and Smart Receiving Techniques
(cont.)

• Spatial diversity
  – Using multiple antennas

• Frequency diversity
  – Providing signal replicas at different carrier frequencies

• Time diversity
  – Providing signal replicas with different arrival times

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Time Diversity Techniques

• Signals arrive at different time delays due to multipath

• The multipath signals can be regarded as a form of diversity

• DSSS and the RAKE receiver
  – Commonly used in DSSS receiver in cellular CDMA

• Traditional modems and equalizers
DSSS and the RAKE Receiver

• In a multipath environment, output at the receiver has several peaks associated with the signals arriving at different path delays.
• To avoid ISI, bit duration must be longer than channel’s multipath spread.
  – Symbol transmission rate is less than the coherence bandwidth of the channel.
• If delay between 2 consecutive paths is significantly less than the chip duration, the 2 paths will merge and appear as 1 path equivalent to the phasor sum of the 2 actual paths.

DSSS and the RAKE Receiver (cont.)

• Multipath Delay Spread

(a) Multipath arrival
DSSS and the RAKE Receiver (cont.)

Channel with 3 multipath components

Figure 3.25 The output of a matched filter with signals arriving via multiple paths at the input.

DSSS and the RAKE Receiver (cont.)

- Chip duration is made short enough to resolve individual path
- The RAKE receiver in a DSSS system
  - Combines multipath components as a part of the decision process
  - Each received signal is passed to the tapped-delay line, and then a correlator
  - Outputs of correlators are fed to diversity combiner
  - The output of the combiner is the estimate of the transmitted information symbol
RAKE Receiver

- A sufficient large number of tapped-delay provides good approximation of all major peaks
- Modern digital receiver has fewer taps but can adjust the tap locations
- Search algorithm for few dominant peaks of the correlation function, and then position the taps accordingly
RAKE Receiver (cont.)

- In DSSS system, multipath does not cause ISI unless the symbol transmission rate approaches the channel’s coherence bandwidth.
- RAKE receivers take advantages of the isolated arriving paths:
  - Improve/optimize system performance.

Traditional Modems and Equalizers

- Equalization
  - If the modulation bandwidth exceeds the coherence bandwidth of the radio channel, ISI occurs and modulation pulses are spread in time.
  - Equalization compensates for intersymbol interference (ISI) created by multipath within time dispersive channels.
  - An equalizer within a receiver compensates for the average range of expected channel amplitude and delay characteristics.
  - Equalizers must be adaptive since the channel is generally unknown and time varying.
Traditional Modems and Equalizers (cont.)

- Use of the training sequence
  - To estimate multipath characteristics and eliminate the effects of ISI \(\rightarrow\) MLSE
  - To design the adaptive filter that inverse channel’s distortion \(\rightarrow\) equalization

- **MLSE** (Maximum likelihood sequence estimation) receiver use trellis diagram with Viterbi algorithm to obtain maximum-likelihood estimates of the transmitted symbols

Adaptive Equalizer

- **Training**
  - Known fixed-length training sequence is sent by the transmitter so that the receiver's equalizer may average to a proper setting
  - The training sequence is designed to permit an equalizer at the receiver to acquire the proper filter coefficients in the worst possible channel conditions
  - Immediately following the training sequence, the user data is sent.
  - Equalizers require periodic retraining in order to maintain effective ISI cancellation.
Adaptive Equalizer (cont.)

- **Tracking**
- As user data are received, the adaptive algorithm of the equalizer tracks the changing channel and adjusts its filter characteristics over time.
- Commonly used in digital communication systems where user data is segmented into short time blocks.
- TDMA wireless systems are particularly well suited for equalizers.
  - Data in fixed-length time blocks, training sequence usually sent at the beginning of a block

Source: https://www.researchgate.net/figure/Figure-Block-Diagram-of-Adaptive-Equalizer_fig11_306035050
Generic Adaptive Equalizer

Maximum Likelihood Sequence Estimator

1. Adaptive channel estimator

2. The MLSE algorithm

Figure 3.27 The adaptive MLSE receiver.
Linear Transversal Equalizer

LTE is better for longer impulse response

Frequency Diversity Techniques

- Frequency selective fading
  - Deep fade of 30-40 dB lower than average
  - The width of the fades is proportional to the delay spread of the multipath arrival
Frequency Diversity Techniques (cont.)

- Surroundings or mobile terminal move, the multipath profile and the frequency selectivity pattern change continually
- FHSS
  - Low power consumption (compared with DHSS)
- Multicarrier system
  - The bandwidth of each carrier is smaller than the coherence bandwidth
  - The number of carriers is large enough
  - There are always a number of carriers that are not affected by deep fade

Frequency Diversity Techniques (cont.)

- Measure the received power in all subcarriers
  - Then reduce transmission rate of the faded subcarrier
  - Or increase transmit power of the faded subcarrier
  - Require feedback channel and channel measurement → cannot use with application with delay-sensitive
Frequency Diversity Techniques (cont.)

• Error correcting code for the transmitted bits in parallel subcarriers
  – No need for feedback channel and channel measurement
  – Low error rate bits in the normal channels are used to correct the high error rate data from subcarriers under deep fade
• Coding technique (useful for FHSS)
  – Encode bits over several hops to recover bits lost during the fade

Space Diversity Technique

• Exploit spatial behavior of the signal
  – Reflections, transmissions, diffractions, scattering patterns that are unique to that path
• Multiple antennas located in different locations
• Multiple antennas with different polarization located in the same location
Space Diversity Technique (cont.)

• A sectored antenna limiting the angle of arrival of the signal
  – Divide the space into several noninterfering zones
    • reduce interference and multipath delay spread
• An antenna array that changes its antenna pattern adaptively (smart antenna)
  – Form a beam toward the target
    • Interference cancellation, control eavesdropping, increase gain, building penetration, longer ranges, reduce near-far effect
Spatial or Antenna Diversity

- Even small antenna separation ($\alpha \lambda$) changes phase of signal
  - Constructive/destructive nature of a signal is changed
  - Polarization Diversity
- Use multiple antennas separated in space
  - At a mobile, signals are independent if separation $> \lambda/2$
  - Not practical to have a mobile with antennas separated by $\lambda/2$
  - Multiple antennas at BS separated on the other to 10 wavelengths

Spatial or Antenna Diversity (cont.)

- At BS, reflection occur near receiver
  - Typical antenna are 120 degree sectoring
  - For each sector, a transmitter antenna is in the center, with 2 diversity receiving antennas on each side.
  - If one radio path undergoes a deep fade, another independent path may have a strong signal.
  - By having more than one path, both the instantaneous and average SNR at the receiver can improve.
Comparison of Modulation Schemes

• Same bandwidth (10 MHz)

![Power requirements of different transmission schemes.](image)

Comparison of Modulation Schemes (cont.)

• Same transmitted power (100mW)

![Maximum achievable data rates with different transmission schemes.](image)
Coding Techniques for Wireless Communications

- Error control coding
- Speech coding
- Code Division Multiple Access
- Complementary codes
  - Increase data rate of spread spectrum transmission

Error Control Coding

- Introduce redundancy in transmitted bits
  - Error Correction
  - Error Detection -> Retransmission, ARQ
- Error in wireless occurs in bursts
- Error in wired occurs at random, one bit at a time
- Application dependent
  - Voice can tolerate BER of $10^{-2}$
  - Data and messaging applications require BER at most $10^{-5}$
Speech Coding

- Transmitted bit rate vs. speech quality
- Lower rate speech code requires less bandwidth for transmission but usually results in low speech quality
- Robustness in the presence of error
- Implementation complexity

Table 3.1  Speech Coders Employed in Some Wireless Systems

<table>
<thead>
<tr>
<th>System</th>
<th>Application</th>
<th>Voice Coder</th>
<th>Uncoded Rate</th>
<th>Overall Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSM</td>
<td>European digital cellular (2G)</td>
<td>RPE-LTP</td>
<td>13 kbps</td>
<td>22.8 kbps</td>
</tr>
<tr>
<td>IS-136</td>
<td>U.S. digital cellular (2G)</td>
<td>VSELP</td>
<td>8 kbps</td>
<td>13 kbps</td>
</tr>
<tr>
<td>JDC</td>
<td>Japanese digital cellular (2G)</td>
<td>VSELP</td>
<td>8 kbps</td>
<td>13 kbps</td>
</tr>
<tr>
<td>IS-95</td>
<td>U.S. and other digital cellular</td>
<td>QCELP</td>
<td>9.6, 4.8, 2.4 and 1.2 kbps</td>
<td>28.8 or 19.2 kbps (FEC + repetition)</td>
</tr>
<tr>
<td></td>
<td>CDMA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DCS-1800</td>
<td>PCS in the United States</td>
<td>RPE-LTP</td>
<td>13 kbps</td>
<td>22.8 kbps</td>
</tr>
<tr>
<td>PHS</td>
<td>Personal handiphone in Japan</td>
<td>ADPCM</td>
<td>32 kbps</td>
<td>32 kbps</td>
</tr>
<tr>
<td>CT-2</td>
<td>European cordless</td>
<td>ADPCM</td>
<td>32 kbps</td>
<td>32 kbps</td>
</tr>
<tr>
<td>DECT</td>
<td>Cordless and WPBX</td>
<td>ADPCM</td>
<td>32 kbps</td>
<td>32 kbps</td>
</tr>
</tbody>
</table>
Coding for Spread Spectrum Systems

• PN (pseudonoise) spreading code
  – Pseudorandom sequence
  – Code for spreading bits (spread spectrum)
  – The sequences are not random but appear random (almost equal no. of zeros and ones)

• Orthogonal Code
  – PN sequences cause interference (non-zero sibelobe)
  – Cross-correlation between two orthogonal sequences is zero when synchronized
  – The users MUST be synchronized
  – Hence, Orthogonal sequences in downlink (BS can synchronize transmission), PN sequences in uplink

Question & Discussion

Assignment

Resources

• https://www.slideshare.net/vrinevimal/equalisation-diversity-coding
• http://course.sdu.edu.cn/G2S/eWebEditor/uploadfile/20121213093035437.pdf