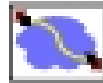


Diversity Techniques



- Distribute signal over multiple "channels".
 - Channels experience independent fading
 - Reduces the error, i.e. only part of the signal is affected
- Time diversity: spread data out over time.
 - Useful for bursty errors, e.g. slow fading
- Space diversity: use multiple nearby antennas and combine signals.
 - Can be directional
- Frequency diversity: spread signal over a multiple frequencies.
 - For example, spread spectrum

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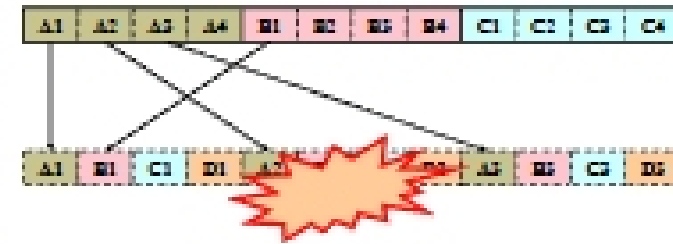
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Time Diversity



- Spread blocks out over time.
- Can use FEC or other error recovery techniques to deal with burst errors.



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Channel Coding



- Channel coding protects digital data by introducing redundancy in the transmitted data.
 - Error detection codes: can identify certain types of errors
 - Error correction codes: can fix certain types of errors
- Block codes provide Forward Error Correction (FEC) for blocks of data.
 - (n, k) code: n bits are transmitted for k information bits
 - Simplest example: parity codes
 - Many different codes exist: Hamming, cyclic, Reed-Solomon, ...

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Space Diversity



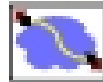
- Use multiple antennas that pick up the signal in slightly different locations.
 - If there is no direct path (Rayleigh), chances are that the signals are mostly uncorrelated
 - Antennas should be separated by $\frac{1}{2}$ wavelength or more
 - If one antenna experiences deep fading, chances are that the other antenna has a strong signal
 - Can use more than two antennas
- Multiple space diversity reception methods:
 - Selection diversity: pick antenna with best SNR
 - Feedback/canonical: only switch if signal becomes weak
 - Maximal ratio combining: combine signals with a weight that is based on their SNR
- MIMO: multiple in multiple out.
 - Also have multiple transmitting antennas

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Spread Spectrum and CDMA



- **Basic idea:** Use a wider bandwidth than needed to transmit the signal.
- **Why??**
 - Don't put all your eggs in one basket!
 - Resistance to jamming and interference
 - If one sub-channel is blocked, you still have the others
 - Good for military
 - Minimize impact of a "bad" frequency
 - Pseudo-encryption
 - Have to know what frequencies it will use
- Two techniques for spread spectrum...

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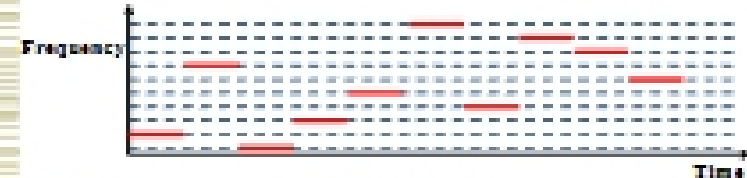
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Frequency Hopping SS



- Pick a set of frequencies within a band
- At each time slot, pick a new frequency
 - Ex: original 11mbit 802.11 used 300ms time slots
 - Each frequency has the bandwidth of the original signal
- Dwell time is the time spent using one frequency
- Spreading code determines the hopping sequence
 - Must be shared by sender and receiver (e.g. standardized)
 - Usually frequency determined by a pseudorandom generator function with a shared seed

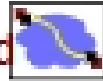


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Example: Original 802.11 Standard



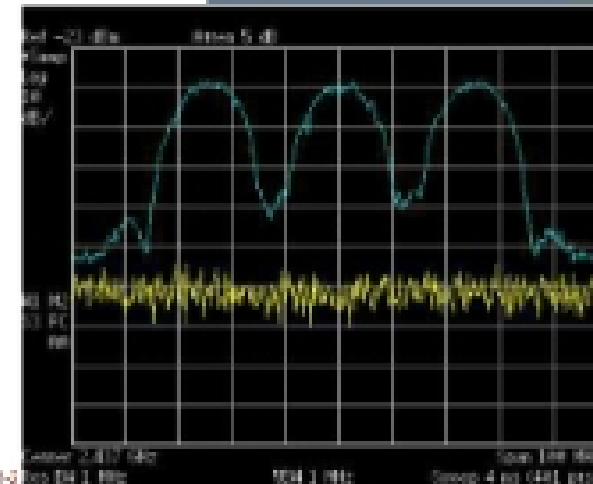
- Used frequency hopping.
- 96 channels of 1 MHz (only 78 used in US).
 - Each channel carries only ~1% of the bandwidth
- The dwell time is 390 msec.
 - transmitter/receiver must be synchronized!
- Standard defined 26 orthogonal hop sequences.
- Transmitter used a beacon on fixed frequency to inform the receiver of the hop sequence that will be used.
- Can support multiple simultaneous transmissions – use different hop sequences.

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802.11 Spectrogram



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