Digital Communication Systems Engineering with Software-Defined Radio

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Lecture 18

What is a Cyclic Extension?

- It is essentially a copy of the last R samples of a symbol that are added to the beginning of the symbol to serve as a *buffer* against channel dispersion
- This is needed to keep successive blocks of transmitted information separate from one another to allow demodulation

ISI Due to Multipath Propagation

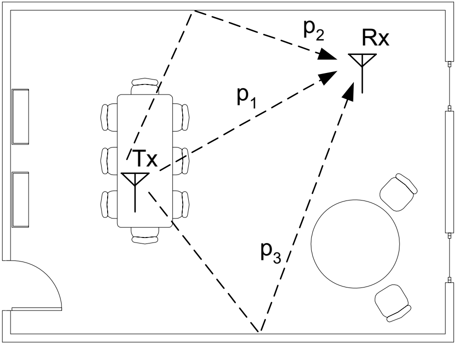

Figure : Example of Indoor Multipath Propagation.

Cyclic Prefix Inclusion

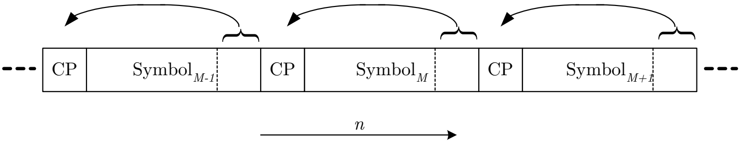

Figure : Add Cyclic Prefix to an OFDM Symbol.

Capturing ISI Effects

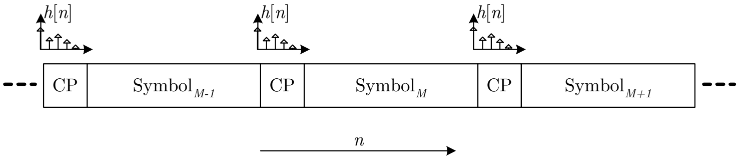

Figure : Smearing by Channel $h(n)$ from Previous Symbol into Cyclic Prefix.

Cyclic Prefix Removal

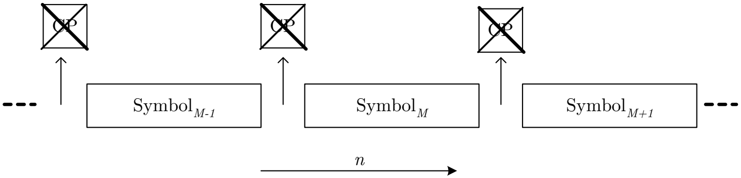

Figure : Removal of Cyclic Prefix.

"Divide-by-Conquer" Revisited

- Notice how multicarrier modulation employs a "divide-by-conquer" approach to data transmission
  - Information is split between N subcarriers that are essentially independent of one another
  - Subcarrier parameters such as modulation scheme, data rate, transmit power, coding rate, and equalizer lengths can all be tailored to the prevailing channel conditions
  - In this course, we will look at tailoring the subcarrier modulation scheme to maximize the aggregate data rate

Adaptive Commutator Approach

- The conversion of bits into modulated symbols can enable variable subcarrier data rates
- The process of performing bit allocation involves the use of an *adaptive commutator* rather than a conventional commutator
  - Bits from the high data rate information stream are non-uniformly allocated across all subcarriers
  - Subcarrier modulation schemes and mapping of bits to symbols may vary across subcarriers

Commutator Models

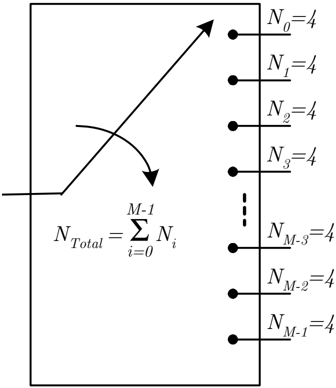

Figure : Conventional Commutator.

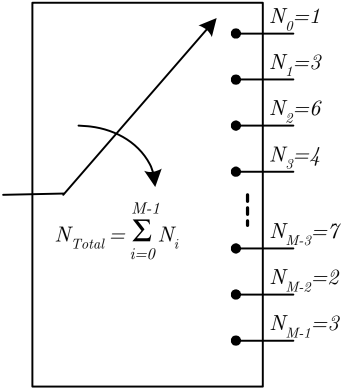

Figure : Adaptive Commutator.

Performing Bit Allocation

- The receiver must be made aware of the subcarrier modulation schemes employed at the transmitter in order to successfully demodulate and combine the data streams
  - "Overhead" channels between transmitters and receivers is a must!
- The tricky part of bit allocation is how to assign the modulation schemes to each subcarrier
  - Maximize data rate subject to error robustness constraint, i.e.:

$$R = \max_{\{b_i\}} \sum_{i=0}^{N-1} b_i \qquad \text{subject to} \qquad P_e = \frac{1}{N} \sum_{i=0}^{N-1} P_e(\gamma_i, b_i)$$

- How do we accomplish this task?
  - Use closed-form or approximate expressions for the probability of error P_e of the available modulation schemes

Capacity-Based Approach

- One popular approach developed by researchers at Stanford University (John Cioffi et al.) used the capacity expression developed by Claude Shannon in conjunction with the concept of the *SNR Gap*
  - Recall that for error-free communications, we have:
    $$C = W \log_2(1+\gamma) \quad (1)$$
    where γ is the signal-to-noise ratio (SNR) and W is the bandwidth
  - Assuming some distance from the maximum number of bits that can be sustained by a system and a given target probability of error P_T, the maximum number of bits that can be sustained with error P_T is equal to:
    $$b_i = \log_2\left(1 + \frac{\gamma_i}{\Gamma}\right) \quad (2)$$
    where $\Gamma \approx \frac{1}{3}[Q^{-1}(P_T/4)]^2$ is the *SNR Gap* that can computed using the union bound on P_T

Other Bit Allocation Approaches

- What is the problem with the capacity-based approach?
  - b_i is a real number and may not be an integer
  - b_i is computed using an approximation of Γ
- Other heuristic techniques exist that enable efficient bit allocation